Title of the Invention

RECOMBINANT PROTEINS OF A PAKISTANI STRAIN OF HEPATITIS E AND THEIR USE IN DIAGNOSTIC METHODS AND VACCINES

Field Of Invention

The invention is in the field of hepatitis virology. More specifically, this invention relates to recombinant proteins derived from an enterically transmitted strain of hepatitis E from Pakistan, SAR-55, and to diagnostic methods and vaccine applications which employ these proteins.

Background of Invention

Epidemics of hepatitis E, an enterically transmitted non-A/non-B hepatitis, have been reported in Asia, Africa and Central America (Balayan, M.S. (1987), Soviet Medical Reviews, Section E, Virology Reviews, Zhdanov, O-V.M. (ed), Chur, Switzerland: Harwood Academic Publishers, vol. 2, 235-261; Purcell, R.G., et al. (1988) in Zuckerman, A.J. (ed), "Viral Hepatitis and Liver Disease", New York: Alan R. Liss, 131-137; Bradley, D.W. (1990), British Medical Bulletin, 46:442-461; Ticehurst, J.R. (1991) in Hollinger, F.B., Lemon, S.M., Margolis, H.S. (eds): "Viral Hepatitis and Liver Disease", Williams and Wilkins, Baltimore, 501-513). Cases of sporadic hepatitis, presumed to be hepatitis E, account for up to 90% of reported hepatitis in countries where hepatitis E virus (HEV) is endemic. The need for development of a serological test for the detection of anti-HEV antibodies in the sera of infected individuals is widely recognized in the field, but the very low concentration of HEV excreted from infected humans or animals made it impossible to use such HEV as the source of antigen for serological tests and although limited success was reported in propagation of HEV in cell culture (Huang, R.T. et al. (1992), J. Gen. Virol., 73:1143-1148), cell culture is currently too

inefficient to produce the amounts of antigen required for serological tests.

Recently, major efforts worldwide to identify viral genomic sequences associated with hepatitis E have resulted in the cloning of the genomes of a limited number of strains of HEV (Tam, A.W. et al. (1991), Virology, 185:120-131; Tsarev, S.A. et al. (1992), Proc. Natl. Acad. Sci. USA, 89:559-563; Fry, K.E. et al. (1992), Virus Genes, 6:173-185). Analysis of the DNA sequences have led investigators to hypothesize that the HEV genome is organized into three open reading frames (ORFs) and to hypothesize that these ORFs encode intact HEV proteins.

A partial DNA sequence of the genome of an HEV strain from Burma (Myanmar) is disclosed in Reyes et al., 1990, Science, 247:1335-1339. Tam et al., 1991, and Reyes et al., PCT Patent Application WO91/15603 published October 17, 1991 disclose the complete nucleotide sequence and a deduced amino acid sequence of the Burma strain of HEV. These authors hypothesized that three forward open reading frames (ORFs) are contained within the sequence of this strain.

Ichikawa et al., 1991, Microbiol. Immunol., 35:535-543, discloses the isolation of a series of clones of 240-320 nucleotides in length upon the screening of a λgt11 expression library with sera from HEV-infected cynomolgus monkeys. The recombinant protein expressed by one clone was expressed in E. coli. This fusion protein is encoded by the 3' region of ORF-2 of the Myanmar strain of HEV.

The expression of additional proteins encoded within the 3' region of ORF-2 of a Mexican strain of HEV and of a Burmese strain of HEV is described in Yarbough et al., 1991 J. Virology, 65:5790-5797. This article describes the isolation of two cDNA clones derived from HEV. These clones encode the proteins in the 3' region of ORF-2. The clones were expressed in E. coli as fusion proteins.

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Purdy et al., 1992, Archives of Virology, 123:335-349, and Favorov et al., 1992, J. of Medical Virology, 36:246-250, disclose the expression of a larger ORF-2 protein fragment from the Burma strain in E. coli. These references, as well as those previously discussed, only disclose the expression of a portion of the ORF-2 gene using bacterial expression systems. Successful expression of the full-length ORF-2 protein has not been disclosed until the present invention.

Comparison of the genome organization and morphological structure of HEV is most closely related to the caliciviruses. Of interest, the structural proteins of caliciviruses are encoded by the 3' portion of their genome (Neil, J.d. et al. (1991) J. Virol., 65:5440-5447; and Carter, M.J. et al. (1992), J. Arch. Virol., 122:223-235) and although there is no direct evidence that the 3' terminal part of the HEV genome also encodes the structural proteins, expression of certain small portions of the 3' genome region in bacterial cells resulted in production of proteins reactive with anti-HEV sera in ELISA and Western blots (Yarborough, et al., (1991); Ichikawa et al. (1991); Favorov et al. (1992) and Dawson, G.J. et al. (1992) J. Virol Meth; 38:175-186). However, the function of ORF-2 protein as a structural protein was not proven until the present invention.

The small proteins encoded by a portion of the ORF-2 gene have been used in immunoassay to detect antibodies to HEV in animal sera. The use of small bacterially expressed proteins as antigens in serological immunoassays has several potential drawbacks. first, the expression of these small proteins in bacterial cells of results in solubility problems and in non-specific cross-reactivity of patients' sera with E. coli proteins when crude E. coli lysates are used as antigens in immunoassays (Purdy et al. (1992)). Second, the use of Western blots as a first-line serological test for anti-HEV antibodies in

routine epidemiology is impractical due to time and cost constraints. An ELISA using small-peptides derived from the 3'-terminal part of the HEV genome resulted in the detection of only 41% positives from known HEV-infected patients. Third, it has been shown that for many viruses, including *Picornaviridae*, important antigenic and immunogenic epitopes are highly conformation (Lemon, S.M. et al. (1991), in Hollinger, F.B., Lemon, S.M., Margolis, H.S. (eds): "Viral Hepatitis and Liver disease", Williams and Wilkins, Baltimore, 20-24). For this reason, it is believed that expression in a eukaryotic system of a complete ORF encoding an intact HEV gene would result in production of a protein which could form HEV-virus-like particles. Such a complete ORF protein would have an immunological structure closer to that of native capsid protein(s) than would the above-noted smaller proteins which represent only portions of the structural proteins of HEV. Therefore, these complete ORF proteins would likely serve as a more representative antigen and a more efficient immunogen than the currently-used smaller proteins.

Summary Of Invention

The present invention relates to an isolated and substantially pure preparation of a human hepatitis E viral strain SAR-55.

The invention also relates to an isolated and substantially pure preparation of the genomic RNA of the human hepatitis E viral strain SAR-55.

The invention further relates to the cDNA of the human hepatitis E viral strain SAR-55.

It is an object of this invention to provide synthetic nucleic acid sequences capable of directing production of recombinant HEV proteins, as well as equivalent natural nucleic acid sequences. Such natural nucleic acid sequences may be isolated from a cDNA or genomic library from which the gene capable of directing synthesis of the HEV proteins may be identified and

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isolated. For purpose of this application, nucleic acid sequence refers to RNA, DNA, cDNA or any synthetic variant thereof which encodes for protein.

The invention further relates to a method for detection of the hepatitis E virus in biological samples based on selective amplification of hepatitis E gene fragments utilizing primers derived from the SAR-55 cDNA.

The invention also relates to the use of single-stranded antisense poly-or oligonucleotides derived from the SAR-55 cDNA to inhibit the expression of hepatitis E genes.

The invention also relates to isolated and substantially purified HEV proteins and variants thereof encoded by the HEV genome of SAR-55 or encoded by synthetic nucleic acid sequences and in particular to recombinant proteins encoded by an open reading frame 2 sequence of HEV.

The invention also relates to the method of preparing recombinant HEV proteins derived from an HEV genomic sequence by cloning the nucleic acid and inserting the cDNA into an expression vector and expressing the recombinant protein in a host cell.

The invention also relates to the use of the resultant recombinant HEV proteins as diagnostic agents and as vaccines.

The present invention also encompasses methods of detecting antibodies specific for hepatitis E virus in biological samples. Such methods are useful for diagnosis of infection and disease caused by HEV, and for monitoring the progression of such disease. Such methods are also useful for monitoring the efficacy of therapeutic agents during the course of treatment of HEV infection and disease in a mammal.

This invention also relates to pharmaceutical compositions for use in prevention or treatment of Hepatitis E in a mammal.

Description Of Figures

Figure 1 shows the recombinant vector used to express the complete ORF-2 protein of the genome of HEV strain SAR-55.

Figures 2A and 2B are sodium dodecyl sulfate-polyacrylamide gels (SDS-PAGE) in which cell lysates of insect cells infected with wild-type baculovirus or recombinant baculovirus (containing the gene encoding ORF-2) were either stained with Coomassie blue (A) or subjected to Western blotting with serum of an HEV-infected chimp (B). In both Figures 2A and 2B, lane 1 contains total cell lysate of noninfected SF-9 cells; lane 2 contains lysate of cells infected with wild-type baculovirus; lane 3 contains lysate of cells infected with recombinant baculovirus and lane 4 contains molecular weight markers.

Figures 3A-1 to 3A-4 and 3B show immunoelectron micrographs (IEM) of 30 and 20 nm virus-like particles respectively, which are formed as a result of the expression of ORF-2 protein in recombinantly infected insect cells.

Figures 4A-4D show the results of an ELISA using as the antigen, recombinant ORF-2 which was expressed from insect cells containing the gene encoding the complete ORF-2. Serum anti-HEV antibody levels were determined at various times following inoculation of cynomolgus monkeys with either the Mexican (Cyno-80A82 (Fig. 4A), Cyno-9A97 (Fig. 4B) and Cyno 83 (Fig. 4C)) or Pakistani (Cyno-374 (Fig. 4D)) strains of HEV.

Figures 5A-D show the results of an ELISA using as the antigen, recombinant ORF-2 which was expressed from insect cells containing the gene encoding the complete ORF-2. Serum IgG or IgM anti-HEV levels were determined over time following inoculation of two chimpanzees with HEV.

Figures 6A-J show a comparison of ELISA data obtained using as the antigen the recombinant complete ORF-2 protein derived from SAR-55 as the antigen vs. a recombinant partial ORF-2 protein derived from the Burma strain of HEV (Genelabs).

Figures 7A-J show anti-HEV IgG ELISA and alanine aminotransferase (ALT) values for cynomolgus monkeys inoculated with ten-fold serial dilutions (indicated in parenthesis at the top of each panel) of a 10% fecal suspension of SAR-55 HEV. Recombinant antigens used in ELISA were: glutathione-S-transferase (GST); 3-2(M), a fusion of the 3-2 epitope [Yarbough et al., (1991) J. Virol, 65:5790-5797] and GST; SG3 (B), a fusion of 327 C-terminal amino acids of ORF-2 and GST [Yarbough et al., (1993): Assay Development of diagnostic tests for Hepatitis E in "International Symposium on Viral Hepatitis and Liver Disease. Scientific Program and Abstract Volume." Tokyo:VHFL p. 87]; and a 55 kDa ORF-2 product directly expressed in insect cells.

Figures 8A-E show anti-HEV IgM ELISA and ALT values for positive cynomolgus monkeys inoculated with ten-fold serial dilutions (indicated in parenthesis at the top of each panel) of the 10% fecal suspension of SAR-55 HEV. Recombinant antigens used in ELISA were: glutathione-S-transferase (GST); 3-2(M), a fusion of the 3-2 epitope [Yarbough et al., 1991] and (GST); SG3 (B), a fusion of 327 C-terminal amino acids of ORF-2 and GST [Yarbough et al., 1993]; and the 55 kDa ORF-2 product directly expressed in insect cells.

Figure 9 shows an ethidium bromide stain of a 2% agarose gel on which PCR products produced from extracts of serial ten-fold dilutions (indicated at the top of each lane of the gel) of the 10% fecal suspension of the SAR-55 HEV were separated. The predicted length of the PCR products was about 640 base pairs and the column marked with an (M) contains DNA size markers.

Figure 10 shows the pPIC9 vector used to express the complete ORF-2 protein or lower molecular weight fragments in yeast.

Figure 11 shows the schematic organization of the hepatitis E virus (HEV) genome and recombinant baculoviruses

encoding full-length (bHEV ORF2 fl) and truncated HEV ORF2 (bHEV ORF2 5′ tr and bHEV ORF2 5′-3′ tr) capsid genes.

Figures 12A and 12B show the temporal protein expression of recombinant baculovirus encoding the HEV ORF2 full-length gene. Sf-9 insect cells were infected at a multiplicity of infection (MOI) = 5 with bHEV ORF2 *fl* virus. Infected cells and media supernatants were harvested daily over the four day infection. Cell lysates and media supernatants were fractionated by SDS-PAGE on 8 - 16% protein gradient gels and stained with colloidal Coomassie blue dye (Figure 12A). Proteins from duplicate protein gels were transferred onto nitrocellulose membranes by electroblotting and HEV proteins were detected chromogenically by antibody binding (Figure 12B) to primary chimp antisera to HEV (1:500) followed by secondary goat antisera human IgG2 - alkaline phosphatase (1:5000). Lane 1, Sea-blue molecular weight markers; lane 2, mock-infected cells; lane 3, 1 day postinfection (p.i.) cells; lane 4, 2 days p.i. cells; lane 5, 3 days p.i. cells; lane 6, 4 days p.i. cells; lane 7, Sea-blue protein MW markers; lane 8, mock-infected supernatant; lane 9, 1 day p.i. supernatant; lane 10, 2 days p.i. supernatant; lane 11, 3 days p.i. supernatant; lane 12, 4 days p.i. supernatant. Lane assignments are similar for panels A and B.

Figure 13A-13C shows protein chromatography elution profiles of cell lysates from bHEV ORF2 *fl* virus infected insect cells. Figure 13A shows the protein elution profile from anion exchange chromatography on a Q Sepharose Fast Flow strong anion exchange column using 0 - 300 mM linear NaCl gradient in Q loading buffer. Figure 13B shows the protein elution profile of HEV 55 kD protein from peak Q fractions on SOURCE 15 Q High Performance strong anion exchange column using 0 - 300 mM linear NaCl gradient in Q loading buffer. Figure 13C shows the elution profile of pooled fractions from SOURCE 15 Q chromatography which contained the 55 kD

protein and which were then subjected to gel filtration on a Sephacryl S 200 column.

Figures 14A and 14B show SDS-PAGE and Western blot results of HEV 55 kD protein contained in gel filtration fractions from a Sephacryl G 200 column. Pooled fractions containing the 55 kD protein from SOURCE 15 Q chromatography of cell lysates were subjected to gel filtration on a Sephacryl S-200 column. Aliquots from selected column fractions were subjected to SDS-PAGE and Western blot analyses (Fig. 14B) ~~lower panel~~) or to a Coomassie blue-stained 8 - 20% NOVEX gradient gel (Fig. 14A ~~upper panel~~). HEV proteins were detected by Western blot with convalescent antisera from HEV-infected chimps. Lane 1, Sea-Blue protein molecular weight markers; lane 2, pooled Q fractions; lanes 3 - 12, gel filtration fractions.

Figure 15 shows the Lys C digestion peptide profile of recombinant HEV ORF2 kD protein purified from cell lysates from Sf-9 insect cells infected with bHEV ORF2 fl virus.

Figure 16 shows the results of carboxyl terminal amino acid analysis of recombinant HEV ORF2 55 kD proteins purified from cell lysates from Sf-9 insect cells infected with bHEV ORF2 fl virus.

Figure 17 shows the electrospray mass spectroscopy profile of the recombinant HEV 55 kD protein purified from cell lysates from Sf-9 insect cells infected with bHEV ORF2 fl virus..

Figures 18A and 18B show the temporal protein expression of recombinant baculoviruses encoding HEV ORF2 genes. Sf-9 insect cells were infected at an MOI = 5 with bHEV ORF2 5' *tr* or 5'-3' *tr* viruses for four days p.i. Infected cells and media supernatants were harvested daily over the four day

infection and analyzed as described in the legend to Figure 12. Figures 18A and B show SDS-PAGE (lanes 1 -5) and Western blot (lanes 6 - 10) results of cell-associated proteins from bHEV ORF2 5' *tr* (Figure 18A) and 5'-3' *tr* (Figure 18B) virus infections, respectively. Figures 18C and D show SDS-PAGE (lanes 1 -5) and Western blot (lanes 6 -10) results of secreted proteins from bHEV ORF2 5' *tr* (Figure 18C) and 5'-3' *tr* (Figure 18D) virus infections, respectively. Lanes 1 and 6, mock-infected cells; lanes 2 and 7, 1 day p.i. cells; lanes 3 and 8, 2 days p.i. cells; lanes 4 and 9, 3 days p.i. cells; and lanes 5 and 10, 4 days p.i. cells.

Sea-blue protein MW markers were used to determine the molecular weight of indicated proteins. Anti-HEV antibody from chimpanzees infected with live HEV was used to detect HEV proteins in Western blots.

Detailed Description of Invention

The present invention relates to an isolated and substantially purified strain of hepatitis E virus (HEV) from Pakistan, SAR-55. The present invention also relates to the cloning of the viral genes encoding proteins of HEV and the expression of the recombinant proteins using an expression system. More specifically, the present invention relates to the cloning and expression of the open reading frames (ORF) of HEV derived from SAR-55.

The present invention relates to isolated HEV proteins. Preferably, the HEV proteins of the present invention are substantially homologous to, and most preferably biologically equivalent to, the native HEV proteins. By "biologically equivalent" as used throughout the specification and claims, it is meant that the compositions are antigenic and/or immunogenic. The HEV proteins of the present invention may also stimulate the production of protective antibodies upon injection into a mammal that would serve to protect the mammal upon challenge with a

wild-type HEV. By "substantially homologous" as used throughout the ensuing specification and claims, is meant a degree of homology in the amino acid sequence to the native HEV proteins. Preferably the degree of homology is in excess of 70%, preferably in excess of 90%, with a particularly preferred group of proteins being in excess of 99% homologous with the native HEV proteins over the region of comparison between the two proteins.

Preferred HEV proteins are those proteins that are encoded by the ORF genes. Of particular interest are proteins encoded by the ORF-2 gene of HEV and most particularly proteins encoded by the ORF-2 gene of the SAR-55 strain of HEV. The amino acid sequences of the ORF-1, ORF-2 and ORF-3 proteins are shown below as SEQ ID NO.: 1, SEQ ID NO.: 2, and SEQ ID NO.: 3, respectively:

(SEQ. ID NO.: 1)

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Met Glu Ala His Gln Phe Ile Lys Ala Pro Gly Ile Thr Thr Ala
1               5                  10                  15
Ile Glu Gln Ala Ala Leu Ala Ala Ala Asn Ser Ala Leu Ala Asn
            20                  25                  30
Ala Val Val Val Arg Pro Phe Leu Ser His Gln Gln Ile Glu Ile
        35                  40                  45
Leu Ile Asn Leu Met Gln Pro Arg Gln Leu Val Phe Arg Pro Glu
    50                  55                  60
Val Phe Trp Asn His Pro Ile Gln Arg Val Ile His Asn Glu Leu
65                  70                  75
Glu Leu Tyr Cys Arg Ala Arg Ser Gly Arg Cys Leu Glu Ile Gly
                80                  85                  90
Ala His Pro Arg Ser Ile Asn Asp Asn Pro Asn Val Val His Arg
            95                  100                 105
Cys Phe Leu Arg Pro Ala Gly Arg Asp Val Gln Arg Trp Tyr Thr
        110                 115                 120
Ala Pro Thr Arg Gly Pro Ala Ala Asn Cys Arg Arg Ser Ala Leu
    125                 130                 135
Arg Gly Leu Pro Ala Ala Asp Arg Thr Tyr Cys Phe Asp Gly Phe
140                 145                 150
Ser Gly Cys Asn Phe Pro Ala Glu Thr Gly Ile Ala Leu Tyr Ser
155                 160                 165
Leu His Asp Met Ser Pro Ser Asp Val Ala Glu Ala Met Phe Arg
            170                 175                 180
His Gly Met Thr Arg Leu Tyr Ala Ala Leu His Leu Pro Pro Glu
        185                 190                 195
Val Leu Leu Pro Pro Gly Thr Tyr Arg Thr Ala Ser Tyr Leu Leu
    200                 205                 210
Ile His Asp Gly Arg Arg Val Val Val Thr Tyr Glu Gly Asp Thr
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                    215                 220                 225
Ser Ala Gly Tyr Asn His Asp Val Ser Asn Leu Arg Ser Trp Ile
                230                 235                 240
Arg Thr Thr Lys Val Thr Gly Asp His Pro Leu Val Ile Glu Arg
                245                 250                 255
Val Arg Ala Ile Gly Cys His Phe Val Leu Leu Leu Thr Ala Ala
                260                 265                 270
Pro Glu Pro Ser Pro Met Pro Tyr Val Pro Tyr Pro Arg Ser Thr
                275                 280                 285
Glu Val Tyr Val Arg Ser Ile Phe Gly Pro Gly Gly Thr Pro Ser
                290                 295                 300
Leu Phe Pro Thr Ser Cys Ser Thr Lys Ser Thr Phe His Ala Val
                305                 310                 315
Pro Ala His Ile Trp Asp Arg Leu Met Leu Phe Gly Ala Thr Leu
                320                 325                 330
Asp Asp Gln Ala Phe Cys Cys Ser Arg Leu Met Thr Tyr Leu Arg
                335                 340                 345
Gly Ile Ser Tyr Lys Val Thr Val Gly Thr Leu Val Ala Asn Glu
                350                 355                 360
Gly Trp Asn Ala Ser Glu Asp Ala Leu Thr Ala Val Ile Thr Ala
                365                 370                 375
Ala Tyr Leu Thr Ile Cys His Gln Arg Tyr Leu Arg Thr Gln Ala
                380                 385                 390
Ile Ser Lys Gly Met Arg Arg Leu Glu Arg Glu His Ala Gln Lys
                395                 400                 405
Phe Ile Thr Arg Leu Tyr Ser Trp Leu Phe Glu Lys Ser Gly Arg
                410                 415                 420
Asp Tyr Ile Pro Gly Arg Gln Leu Glu Phe Tyr Ala Gln Cys Arg
                425                 430                 435
Arg Trp Leu Ser Ala Gly Phe His Leu Asp Pro Arg Val Leu Val
                440                 445                 450
Phe Asp Glu Ser Ala Pro Cys His Cys Arg Thr Ala Ile Arg Lys
                455                 460                 465
Ala Val Ser Lys Phe Cys Cys Phe Met Lys Trp Leu Gly Gln Glu
                470                 475                 480
Cys Thr Cys Phe Leu Gln Pro Ala Glu Gly Val Val Gly Asp Gln
                485                 490                 495
Gly His Asp Asn Glu Ala Tyr Glu Gly Ser Asp Val Asp Pro Ala
                500                 505                 510
Glu Ser Ala Ile Ser Asp Ile Ser Gly Ser Tyr Val Val Pro Gly
                515                 520                 525
Thr Ala Leu Gln Pro Leu Tyr Gln Ala Leu Asp Leu Pro Ala Glu
                530                 535                 540
Ile Val Ala Arg Ala Gly Arg Leu Thr Ala Thr Val Lys Val Ser
                545                 550                 555
Gln Val Asp Gly Arg Ile Asp Cys Glu Thr Leu Leu Gly Asn Lys
                560                 565                 570
Thr Phe Arg Thr Ser Phe Val Asp Gly Ala Val Leu Glu Thr Asn
                575                 580                 585
Gly Pro Glu Arg His Asn Leu Ser Phe Asp Ala Ser Gln Ser Thr
                590                 595                 600
Met Ala Ala Gly Pro Phe Ser Leu Thr Tyr Ala Ala Ser Ala Ala
                605                 610                 615
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Gly Leu Glu Val Arg Tyr Val Ala Ala Gly Leu Asp His Arg Ala
620 625 630
Val Phe Ala Pro Gly Val Ser Pro Arg Ser Ala Pro Gly Glu Val
635 640 645
Thr Ala Phe Cys Ser Ala Leu Tyr Arg Phe Asn Arg Glu Ala Gln
650 655 660
Arg Leu Ser Leu Thr Gly Asn Phe Trp Phe His Pro Glu Gly Leu
665 670 675
Leu Gly Pro Phe Ala Pro Phe Ser Pro Gly His Val Trp Glu Ser
680 685 690
Ala Asn Pro Phe Cys Gly Glu Ser Thr Leu Tyr Thr Arg Thr Trp
695 700 705
Ser Glu Val Asp Ala Val Pro Ser Pro Ala Gln Pro Asp Leu Gly
710 715 720
Phe Thr Ser Glu Pro Ser Ile Pro Ser Arg Ala Ala Thr Pro Thr
725 730 735
Pro Ala Ala Pro Leu Pro Pro Pro Ala Pro Asp Pro Ser Pro Thr
740 745 750
Leu Ser Ala Pro Ala Arg Gly Glu Pro Ala Pro Gly Ala Thr Ala
755 760 765
Arg Ala Pro Ala Ile Thr His Gln Thr Ala Arg His Arg Arg Leu
770 775 780
Leu Phe Thr Tyr Pro Asp Gly Ser Lys Val Phe Ala Gly Ser Leu
785 790 795
Phe Glu Ser Thr Cys Thr Trp Leu Val Asn Ala Ser Asn Val Asp
800 805 810
His Arg Pro Gly Gly Gly Leu Cys His Ala Phe Tyr Gln Arg Tyr
815 820 825
Pro Ala Ser Phe Asp Ala Ala Ser Phe Val Met Arg Asp Gly Ala
830 835 840
Ala Ala Tyr Thr Leu Thr Pro Arg Pro Ile Ile His Ala Val Ala
845 850 855
Pro Asp Tyr Arg Leu Glu His Asn Pro Lys Arg Leu Glu Ala Ala
860 865 870
Tyr Arg Glu Thr Cys Ser Arg Leu Gly Thr Ala Ala Tyr Pro Leu
875 880 885
Leu Gly Thr Gly Ile Tyr Gln Val Pro Ile Gly Pro Ser Phe Asp
890 895 900
Ala Trp Glu Arg Asn His Arg Pro Gly Asp Glu Leu Tyr Leu Pro
905 910 915
Glu Leu Ala Ala Arg Trp Phe Glu Ala Asn Arg Pro Thr Cys Pro
920 925 930
Thr Leu Thr Ile Thr Glu Asp Val Ala Arg Thr Ala Asn Leu Ala
935 940 945
Ile Glu Leu Asp Ser Ala Thr Asp Val Gly Arg Ala Cys Ala Gly
950 955 960
Cys Arg Val Thr Pro Gly Val Val Gln Tyr Gln Phe Thr Ala Gly
965 970 975
Val Pro Gly Ser Gly Lys Ser Arg Ser Ile Thr Gln Ala Asp Val
980 985 990
Asp Val Val Val Val Pro Thr Arg Glu Leu Arg Asn Ala Trp Arg
995 1000 1005
Arg Arg Gly Phe Ala Ala Phe Thr Pro His Thr Ala Ala Arg Val

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                    1010                    1015                    1020
Thr Gln Gly Arg Arg Val Val Ile Asp Glu Ala Pro Ser Leu Pro
                    1025                    1030                    1035
Pro His Leu Leu Leu Leu His Met Gln Arg Ala Ala Thr Val His
                    1040                    1045                    1050
Leu Leu Gly Asp Pro Asn Gln Ile Pro Ala Ile Asp Phe Glu His
                    1055                    1060                    1065
Ala Gly Leu Val Pro Ala Ile Arg Pro Asp Leu Ala Pro Thr Ser
                    1070                    1075                    1080
Trp Trp His Val Thr His Arg Cys Pro Ala Asp Val Cys Glu Leu
                    1085                    1090                    1095
Ile Arg Gly Ala Tyr Pro Met Ile Gln Thr Thr Ser Arg Val Leu
                    1100                    1105                    1110
Arg Ser Leu Phe Trp Gly Glu Pro Ala Val Gly Gln Lys Leu Val
                    1115                    1120                    1125
Phe Thr Gln Ala Ala Lys Ala Ala Asn Pro Gly Ser Val Thr Val
                    1130                    1135                    1140
His Glu Ala Gln Gly Ala Thr Tyr Thr Glu Thr Thr Ile Ile Ala
                    1145                    1150                    1155
Thr Ala Asp Ala Arg Gly Leu Ile Gln Ser Ser Arg Ala His Ala
                    1160                    1165                    1170
Ile Val Ala Leu Thr Arg His Thr Glu Lys Cys Val Ile Ile Asp
                    1175                    1180                    1185
Ala Pro Gly Leu Leu Arg Glu Val Gly Ile Ser Asp Ala Ile Val
                    1190                    1195                    1200
Asn Asn Phe Phe Leu Ala Gly Gly Glu Ile Gly His Gln Arg Pro
                    1205                    1210                    1215
Ser Val Ile Pro Arg Gly Asn Pro Asp Ala Asn Val Asp Thr Leu
                    1220                    1225                    1230
Ala Ala Phe Pro Pro Ser Cys Glu Ile Ser Ala Phe His Glu Leu
                    1235                    1240                    1245
Ala Glu Glu Leu Gly His Arg Pro Ala Pro Val Ala Ala Val Leu
                    1250                    1255                    1260
Pro Pro Cys Pro Glu Leu Glu Gln Gly Leu Leu Tyr Leu Pro Gln
                    1265                    1270                    1275
Glu Leu Thr Thr Cys Asp Ser Val Val Thr Phe Glu Leu Thr Asp
                    1280                    1285                    1290
Ile Val His Cys Arg Met Ala Ala Pro Ser Gln Arg Lys Ala Val
                    1295                    1300                    1305
Leu Ser Thr Leu Val Gly Arg Tyr Gly Arg Arg Thr Lys Leu Tyr
                    1310                    1315                    1320
Asn Ala Ser His Ser Asp Val Arg Asp Ser Leu Ala Arg Phe Ile
                    1325                    1330                    1335
Pro Ala Ile Gly Pro Val Gln Val Thr Thr Cys Glu Leu Tyr Glu
                    1340                    1345                    1350
Leu Glu Glu Ala Met Val Glu Lys Gly Gln Asp Gly Ser Ala Val
                    1355                    1360                    1365
Leu Glu Leu Asp Leu Cys Ser Arg Asp Val Ser Arg Ile Thr Phe
                    1370                    1375                    1380
Phe Gln Lys Asp Cys Asn Lys Phe Thr Thr Gly Glu Thr Ile Ala
                    1385                    1390                    1395
His Gly Lys Val Gly Gln Gly Ile Ser Ala Trp Ser Lys Thr Phe
                    1400                    1405                    1410
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Cys Ala Leu Phe Gly Pro Trp Phe Arg Ala Ile Glu Lys Ala Ile
1415 1420 1425
Leu Ala Leu Leu Pro Gln Gly Val Phe Tyr Gly Asp Ala Phe Asp
1430 1435 1440
Asp Thr Val Phe Ser Ala Ala Val Ala Ala Ala Lys Ala Ser Met
1445 1450 1455
Val Phe Glu Asn Asp Phe Ser Glu Phe Asp Ser Thr Gln Asn Asn
1460 1465 1470
Phe Ser Leu Gly Leu Glu Cys Ala Ile Met Glu Glu Cys Gly Met
1475 1480 1485
Pro Gln Trp Leu Ile Arg Leu Tyr His Leu Ile Arg Ser Ala Trp
1490 1495 1500
Ile Leu Gln Ala Pro Lys Glu Ser Leu Arg Gly Phe Trp Lys Lys
1505 1510 1515
His Ser Gly Glu Pro Gly Thr Leu Leu Trp Asn Thr Val Trp Asn
1520 1525 1530
Met Ala Val Ile Thr His Cys Tyr Asp Phe Arg Asp Leu Gln Val
1535 1540 1545
Ala Ala Phe Lys Gly Asp Asp Ser Ile Val Leu Cys Ser Glu Tyr
1550 1555 1560
Arg Gln Ser Pro Gly Ala Ala Val Leu Ile Ala Gly Cys Gly Leu
1565 1570 1575
Lys Leu Lys Val Asp Phe Arg Pro Ile Gly Leu Tyr Ala Gly Val
1580 1585 1590
Val Val Ala Pro Gly Leu Gly Ala Leu Pro Asp Val Val Arg Phe
1595 1600 1605
Ala Gly Arg Leu Thr Glu Lys Asn Trp Gly Pro Gly Pro Glu Arg
1610 1615 1620
Ala Glu Gln Leu Arg Leu Ala Val Ser Asp Phe Leu Arg Lys Leu
1625 1630 1635
Thr Asn Val Ala Gln Met Cys Val Asp Val Val Ser Arg Val Tyr
1640 1645 1650
Gly Val Ser Pro Gly Leu Val His Asn Leu Ile Glu Met Leu Gln
1655 1660 1665
Ala Val Ala Asp Gly Lys Ala His Phe Thr Glu Ser Val Lys Pro
1670 1675 1680
Val Leu Asp Leu Thr Asn Ser Ile Leu Cys Arg Val Glu
1685 1690

(SEQ. ID NO.: 2)

Met Arg Pro Arg Pro Ile Leu Leu Leu Leu Leu Met Phe Leu Pro
1 5 10 15
Met Leu Pro Ala Pro Pro Pro Gly Gln Pro Ser Gly Arg Arg Arg
20 25 30
Gly Arg Arg Ser Gly Gly Ser Gly Gly Gly Phe Trp Gly Asp Arg
35 40 45
Val Asp Ser Gln Pro Phe Ala Ile Pro Tyr Ile His Pro Thr Asn
50 55 60
Pro Phe Ala Pro Asp Val Thr Ala Ala Ala Gly Ala Gly Pro Arg
65 70 75
Val Arg Gln Pro Ala Arg Pro Leu Gly Ser Ala Trp Arg Asp Gln

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                    80                  85                  90
Ala Gln Arg Pro Ala Ala Ala Ser Arg Arg Arg Pro Thr Thr Ala
                    95                 100                 105
Gly Ala Ala Pro Leu Thr Ala Val Ala Pro Ala His Asp Thr Pro
                   110                 115                 120
Pro Val Pro Asp Val Asp Ser Arg Gly Ala Ile Leu Arg Arg Gln
                   125                 130                 135
Tyr Asn Leu Ser Thr Ser Pro Leu Thr Ser Ser Val Ala Thr Gly
                   140                 145                 150
Thr Asn Leu Val Leu Tyr Ala Ala Pro Leu Ser Pro Leu Leu Pro
                   155                 160                 165
Leu Gln Asp Gly Thr Asn Thr His Ile Met Ala Thr Glu Ala Ser
                   170                 175                 180
Asn Tyr Ala Gln Tyr Arg Val Ala Arg Ala Thr Ile Arg Tyr Arg
                   185                 190                 195
Pro Leu Val Pro Asn Ala Val Gly Gly Tyr Ala Ile Ser Ile Ser
                   200                 205                 210
Phe Tyr Pro Gln Thr Thr Thr Thr Pro Thr Ser Val Asp Met Asn
                   215                 220                 225
Ser Ile Thr Ser Thr Asp Val Arg Ile Leu Val Gln Pro Gly Ile
                   230                 235                 240
Ala Ser Glu Leu Val Ile Pro Ser Glu Arg Leu His Tyr Arg Asn
                   245                 250                 255
Gln Gly Trp Arg Ser Val Glu Thr Ser Gly Val Ala Glu Glu Glu
                   260                 265                 270
Ala Thr Ser Gly Leu Val Met Leu Cys Ile His Gly Ser Pro Val
                   275                 280                 285
Asn Ser Tyr Thr Asn Thr Pro Tyr Thr Gly Ala Leu Gly Leu Leu
                   290                 295                 300
Asp Phe Ala Leu Glu Leu Glu Phe Arg Asn Leu Thr Pro Gly Asn
                   305                 310                 315
Thr Asn Thr Arg Val Ser Arg Tyr Ser Ser Thr Ala Arg His Arg
                   320                 325                 330
Leu Arg Arg Gly Ala Asp Gly Thr Ala Glu Leu Thr Thr Thr Ala
                   335                 340                 345
Ala Thr Arg Phe Met Lys Asp Leu Tyr Phe Thr Ser Thr Asn Gly
                   350                 355                 360
Val Gly Glu Ile Gly Arg Gly Ile Ala Leu Thr Leu Phe Asn Leu
                   365                 370                 375
Ala Asp Thr Leu Leu Gly Gly Leu Pro Thr Glu Leu Ile Ser Ser
                   380                 385                 390
Ala Gly Gly Gln Leu Phe Tyr Ser Arg Pro Val Val Ser Ala Asn
                   395                 400                 405
Gly Glu Pro Thr Val Lys Leu Tyr Thr Ser Val Glu Asn Ala Gln
                   410                 415                 420
Gln Asp Lys Gly Ile Ala Ile Pro His Asp Ile Asp Leu Gly Glu
                   425                 430                 435
Ser Arg Val Val Ile Gln Asp Tyr Asp Asn Gln His Glu Gln Asp
                   440                 445                 450
Arg Pro Thr Pro Ser Pro Ala Pro Ser Arg Pro Phe Ser Val Leu
                   455                 460                 465
Arg Ala Asn Asp Val Leu Trp Leu Ser Leu Thr Ala Ala Glu Tyr
                   470                 475                 480
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Asp Gln Ser Thr Tyr Gly Ser Ser Thr Gly Pro Val Tyr Val Ser
                485                 490                 495
Asp Ser Val Thr Leu Val Asn Val Ala Thr Gly Ala Gln Ala Val
            500                 505                 510
Ala Arg Ser Leu Asp Trp Thr Lys Val Thr Leu Asp Gly Arg Pro
        515                 520                 525
Leu Ser Thr Ile Gln Gln Tyr Ser Lys Thr Phe Phe Val Leu Pro
    530                 535                 540
Leu Arg Gly Lys Leu Ser Phe Trp Glu Ala Gly Thr Thr Lys Ala
545                 550                 555
Gly Tyr Pro Tyr Asn Tyr Asn Thr Thr Ala Ser Asp Gln Leu Leu
            560                 565                 570
Val Glu Asn Ala Ala Gly His Arg Val Ala Ile Ser Thr Tyr Thr
        575                 580                 585
Thr Ser Leu Gly Ala Gly Pro Val Ser Ile Ser Ala Val Ala Val
    590                 595                 600
Leu Ala Pro His Ser Val Leu Ala Leu Leu Glu Asp Thr Met Asp
605                 610                 615
Tyr Pro Ala Arg Ala His Thr Phe Asp Asp Phe Cys Pro Glu Cys
            620                 625                 630
Arg Pro Leu Gly Leu Gln Gly Cys Ala Phe Gln Ser Thr Val Ala
        635                 640                 645
Glu Leu Gln Arg Leu Lys Met Lys Val Gly Lys Thr Arg Glu Leu
    650                 655                 660
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(SEQ. ID NO.: 3)

```
Met Asn Asn Met Ser Phe Ala Ala Pro Met Gly Ser Arg Pro Cys
1               5                  10                  15
Ala Leu Gly Leu Phe Cys Cys Cys Ser Ser Cys Phe Cys Leu Cys
            20                  25                  30
Cys Pro Arg His Arg Pro Val Ser Arg Leu Ala Ala Val Val Gly
        35                  40                  45
Gly Ala Ala Ala Val Pro Ala Val Val Ser Gly Val Thr Gly Leu
    50                  55                  60
Ile Leu Ser Pro Ser Gln Ser Pro Ile Phe Ile Gln Pro Thr Pro
65                  70                  75
Ser Pro Pro Met Ser Pro Leu Arg Pro Gly Leu Asp Leu Val Phe
            80                  85                  90
Ala Asn Pro Pro Asp His Ser Ala Pro Leu Gly Val Thr Arg Pro
        95                 100                 105
Ser Ala Pro Pro Leu Pro His Val Val Asp Leu Pro Gln Leu Gly
    110                 115                 120
Pro Arg Arg
```

The three-letter abbreviations follow the conventional amino acid shorthand for the twenty naturally occurring amino acids.

The preferred recombinant HEV proteins consist of at least one ORF protein. Other recombinant proteins made

up of more than one of the same or different ORF proteins may be made to alter the biological properties of the protein. It is contemplated that additions, substitutions or deletions of discrete amino acids or of discrete sequences of amino acids may enhance the biological activity of the HEV proteins.

The present invention is also a nucleic acid sequence which is capable of directing the production of the above-discussed HEV protein or proteins substantially homologous to the HEV proteins. This nucleic acid sequence, designated SAR-55, is set forth below as SEQ ID NO.: 4 and was deposited with the American Type Culture Collection (ATCC) on September 17, 1992 (ATCC accession number 75302).

T190X

AGGCAGACCA CATATGTGGT CGATGCCATG GAGGCCCATC	40
AGTTTATCAA GGCTCCTGGC ATCACTACTG CTATTGAGCA	80
GGCTGCTCTA GCAGCGGCCA ACTCTGCCCT TGCGAATGCT	120
GTGGTAGTTA GGCCTTTTCT CTCTCACCAG CAGATTGAGA	160
TCCTTATTAA CCTAATGCAA CCTCGCCAGC TTGTTTTCCG	200
CCCCGAGGTT TTCTGGAACC ATCCCATCCA GCGTGTTATC	240
CATAATGAGC TGGAGCTTTA CTGTCGCGCC CGCTCCGGCC	280
GCTGCCTCGA AATTGGTGCC CACCCCCGCT CAATAAATGA	320
CAATCCTAAT GTGGTCCACC GTTGCTTCCT CCGTCCTGCC	360
GGGCGTGATG TTCAGCGTTG GTATACTGCC CCTACCCGCG	400
GGCCGGCTGC TAATTGCCGG CGTTCCGCGC TGCGCGGGCT	440
CCCCGCTGCT GACCGCACTT ACTGCTTCGA CGGGTTTTCT	480
GGCTGTAACT TTCCCGCCGA GACGGGCATC GCCCTCTATT	520
CTCTCCATGA TATGTCACCA TCTGATGTCG CCGAGGCTAT	560
GTTCCGCCAT GGTATGACGC GGCTTTACGC TGCCCTCCAC	600
CTCCCGCCTG AGGTCCTGTT GCCCCCTGGC ACATACCGCA	640
CCGCGTCGTA CTTGCTGATC CATGACGGCA GGCGCGTTGT	680
GGTGACGTAT GAGGGTGACA CTAGTGCTGG TTATAACCAC	720
GATGTTTCCA ACCTGCGCTC CTGGATTAGA ACCACTAAGG	760
TTACCGGAGA CCACCCTCTC GTCATCGAGC GGGTTAGGGC	800
CATTGGCTGC CACTTTGTCC TTTTACTCAC GGCTGCTCCG	840
GAGCCATCAC CTATGCCCTA TGTCCCTTAC CCCCGGTCTA	880

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CCGAGGTCTA TGTCCGATCG ATCTTCGGCC CGGGTGGCAC   920
CCCCTCCCTA TTTCCAACCT CATGCTCCAC CAAGTCGACC   960
TTCCATGCTG TCCCTGCCCA TATCTGGGAC CGTCTCATGT  1000
TGTTCGGGGC CACCCTAGAT GACCAAGCCT TTTGCTGCTC  1040
CCGCCTAATG ACTTACCTCC GCGGCATTAG CTACAAGGTT  1080
ACTGTGGGCA CCCTTGTTGC CAATGAAGGC TGGAACGCCT  1120
CTGAGGACGC TCTTACAGCT GTCATCACTG CCGCCTACCT  1160
TACCATCTGC CACCAGCGGT ACCTCCGCAC TCAGGCTATA  1200
TCTAAGGGGA TGCGTCGCCT GGAGCGGGAG CATGCTCAGA  1240
AGTTTATAAC ACGCCTCTAC AGTTGGCTCT TTGAGAAGTC  1280
CGGCCGTGAT TATATCCCCG GCCGTCAGTT GGAGTTCTAC  1320
GCTCAGTGTA GGCGCTGGCT CTCGGCCGGC TTTCATCTTG  1360
ACCCACGGGT GTTGGTTTTT GATGAGTCGG CCCCCTGCCA  1400
CTGTAGGACT GCGATTCGTA AGGCGGTCTC AAAGTTTTGC  1440
TGCTTTATGA AGTGGCTGGG CCAGGAGTGC ACCTGTTTTC  1480
TACAACCTGC AGAAGGCGTC GTTGGCGACC AGGGCCATGA  1520
CAACGAGGCC TATGAGGGGT CTGATGTTGA CCCTGCTGAA  1560
TCCGCTATTA GTGACATATC TGGGTCCTAC GTAGTCCCTG  1600
GCACTGCCCT CCAACCGCTT TACCAAGCCC TTGACCTCCC  1640
CGCTGAGATT GTGGCTCGTG CAGGCCGGCT GACCGCCACA  1680
GTAAAGGTCT CCCAGGTCGA CGGGCGGATC GATTGTGAGA  1720
CCCTTCTCGG TAATAAAACC TTCCGCACGT CGTTTGTTGA  1760
CGGGGCGGTT TTAGAGACTA ATGGCCCAGA GCGCCACAAT  1800
CTCTCTTTTG ATGCCAGTCA GAGCACTATG GCCGCCGGCC  1840
CTTTCAGTCT CACCTATGCC GCCTCTGCTG CTGGGCTGGA  1880
GGTGCGCTAT GTCGCCGCCG GGCTTGACCA CCGGGCGGTT  1920
TTTGCCCCCG GCGTTTCACC CCGGTCAGCC CCTGGCGAGG  1960
TCACCGCCTT CTGTTCTGCC CTATACAGGT TTAATCGCGA  2000
GGCCCAGCGC CTTTCGCTGA CCGGTAATTT TTGGTTCCAT  2040
CCTGAGGGGC TCCTTGGCCC CTTTGCCCCG TTTTCCCCCG  2080
GGCATGTTTG GGAGTCGGCT AATCCATTCT GTGGCGAGAG  2120
CACACTTTAC ACCCGCACTT GGTCGGAGGT TGATGCTGTT  2160
CCTAGTCCAG CCCAGCCCGA CTTAGGTTTT ACATCTGAGC  2200
CTTCTATACC TAGTAGGGCC GCCACACCTA CCCCGGCGGC  2240
CCCTCTACCC CCCCCTGCAC CGGATCCTTC CCCTACTCTC  2280
TCTGCTCCGG CGCGTGGTGA GCCGGCTCCT GGCGCTACCG  2320
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CCAGGGCCCC AGCCATAACC CACCAGACGG CCCGGCATCG 2360
CCGCCTGCTC TTTACCTACC CGGATGGCTC TAAGGTGTTC 2400
GCCGGCTCGC TGTTTGAGTC GACATGTACC TGGCTCGTTA 2440
ACGCGTCTAA TGTTGACCAC CGCCCTGGCG GTGGGCTCTG 2480
TCATGCATTT TACCAGAGGT ACCCCGCCTC CTTTGATGCT 2520
GCCTCTTTTG TGATGCGCGA CGGCGCGGCC GCCTACACAT 2560
TAACCCCCCG GCCAATAATT CATGCCGTCG CTCCTGATTA 2600
TAGGTTGGAA CATAACCCAA AGAGGCTTGA GGCTGCCTAC 2640
CGGGAGACTT GCTCCCGCCT CGGTACCGCT GCATACCCAC 2680
TCCTCGGGAC CGGCATATAC CAGGTGCCGA TCGGTCCCAG 2720
TTTTGACGCC TGGGAGCGGA ATCACCGCCC CGGGGACGAG 2760
TTGTACCTTC CTGAGCTTGC TGCCAGATGG TTCGAGGCCA 2800
ATAGGCCGAC CTGCCCAACT CTCACTATAA CTGAGGATGT 2840
TGCGCGGACA GCAAATCTGG CTATCGAACT TGACTCAGCC 2880
ACAGACGTCG GCCGGGCCTG TGCCGGCTGT CGAGTCACCC 2920
CCGGCGTTGT GCAGTACCAG TTTACCGCAG GTGTGCCTGG 2960
ATCCGGCAAG TCCCGCTCTA TTACCCAAGC CGACGTGGAC 3000
GTTGTCGTGG TCCCGACCCG GGAGTTGCGT AATGCCTGGC 3040
GCCGCCGCGG CTTCGCTGCT TTCACCCCGC ACACTGCGGC 3080
TAGAGTCACC CAGGGGCGCC GGGTTGTCAT TGATGAGGCC 3120
CCGTCCCTTC CCCCTCATTT GCTGCTGCTC CACATGCAGC 3160
GGGCCGCCAC CGTCCACCTT CTTGGCGACC CGAATCAGAT 3200
CCCAGCCATC GATTTTGAGC ACGCCGGGCT CGTTCCCGCC 3240
ATCAGGCCCG ATTTGGCCCC CACCTCCTGG TGGCATGTTA 3280
CCCATCGCTG CCCTGCGGAT GTATGTGAGC TAATCCGCGG 3320
CGCATACCCT ATGATTCAGA CCACTAGTCG GGTCCTCCGG 3360
TCGTTGTTCT GGGGTGAGCC CGCCGTTGGG CAGAAGCTAG 3400
TGTTCACCCA GGCGGCTAAG GCCGCCAACC CCGGTTCAGT 3440
GACGGTCCAT GAGGCACAGG GCGCTACCTA CACAGAGACT 3480
ACCATCATTG CCACGGCAGA TGCTCGAGGC CTCATTCAGT 3520
CGTCCCGAGC TCATGCCATT GTTGCCTTGA CGCGCCACAC 3560
TGAGAAGTGC GTCATCATTG ACGCACCAGG CCTGCTTCGC 3600
GAGGTGGGCA TCTCCGATGC AATCGTTAAT AACTTTTTCC 3640
TTGCTGGTGG CGAAATTGGC CACCAGCGCC CATCTGTTAT 3680
CCCTCGCGGC AATCCTGACG CCAATGTTGA CACCTTGGCT 3720
GCCTTCCCGC CGTCTTGCCA GATTAGCGCC TTCCATCAGT 3760
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TGGCTGAGGA GCTTGGCCAC AGACCTGCCC CTGTCGCGGC 3800
TGTTCTACCG CCCTGCCCTG AGCTTGAACA GGGCCTTCTC 3840
TACCTGCCCC AAGAACTCAC CACCTGTGAT AGTGTCGTAA 3880
CATTTGAATT AACAGATATT GTGCATTGTC GTATGGCCGC 3920
CCCGAGCCAG CGCAAGGCCG TGCTGTCCAC GCTCGTGGGC 3960
CGTTATGGCC GCCGCACAAA GCTCTACAAT GCCTCCCACT 4000
CTGATGTTCG CGACTCTCTC GCCCGTTTTA TCCCGGCCAT 4040
TGGCCCCGTA CAGGTTACAA CCTGTGAATT GTACGAGCTA 4080
GTGGAGGCCA TGGTCGAGAA GGGCCAGGAC GGCTCCGCCG 4120
TCCTTGAGCT CGACCTTTGT AGCCGCGACG TGTCCAGGAT 4160
CACCTTCTTC CAGAAAGATT GTAATAAATT CACCACGGGG 4200
GAGACCATCG CCCATGGTAA AGTGGGCCAG GGCATTTCGG 4240
CCTGGAGTAA GACCTTCTGT GCCCTTTTCG GCCCCTGGTT 4280
CCGTGCTATT GAGAAGGCTA TCCTGGCCCT GCTCCCTCAG 4320
GGTGTGTTTT ATGGGGATGC CTTTGATGAC ACCGTCTTCT 4360
CGGCGGCTGT GGCCGCAGCA AAGGCATCCA GAATGACTTT 4400
TCTGAGTTTG ATTCCACCCA GAATAATTTT TCCTTGGGCC 4440
TAGAGTGTGC TATTATGGAG GAGTGTGGGA TGCCGCAGTG 4480
GCTCATCCGC TTGTACCACC TTATAAGGTC TGCGTGGATT 4520
CTGCAGGCCC CGAAGGAGTC CCTGCGAGGG TTTTGGAAGA 4560
AACACTCCGG TGAGCCCGGC ACCCTTCTGT GGAATACTGT 4600
CTGGAACATG GCCGTTATCA CCCACTGTTA TGATTTCCGC 4640
GATCTGCAGG TGGCTGCCTT TAAAGGTGAT GATTCGATAG 4680
TGCTTTGCAG TGAGTACCGT CAGAGCCCAG GGGCTGCTGT 4720
CCTGATTGCT GGCTGTGGCC TAAAGTTGAA GGTGGATTTC 4760
CGTCCGATTG GTCTGTATGC AGGTGTTGTG GTGGCCCCCG 4800
GCCTTGGCGC GCTTCCTGAT GTCGTGCGCT TCGCCGGTCG 4840
GCTTACTGAG AAGAATTGGG GCCCTGGCCC CGAGCGGGCG 4880
GAGCAGCTCC GCCTCGCTGT GAGTGATTTT CTCCGCAAGC 4920
TCACGAATGT AGCTCAGATG TGTGTGGATG TTGTCTCTCG 4960
TGTTTATGGG GTTTCCCCTG GGCTCGTTCA TAACCTGATT 5000
GGCATGCTAC AGGCTGTTGC TGATGGCAAG GCTCATTTCA 5040
CTGAGTCAGT GAAGCCAGTG CTTGACCTGA CAAATTCAAT 5080
TCTGTGTCGG GTGGAATGAA TAACATGTCT TTTGCTGCGC 5120
CCATGGGTTC GCGACCATGC GCCCTCGGCC TATTTTGCTG 5160
TTGCTCCTCA TGTTTCTGCC TATGCTGCCC GCGCCACCGC 5200

CCGGTCAGCC GTCTGGCCGC CGTCGTGGGC GGCGCAGCGG 5240
CGGTTCCGGC GGTGGTTTCT GGGGTGACCG GGTTGATTCT 5280
CAGCCCTTCG CAATCCCCTA TATTCATCCA ACCAACCCCT 5320
TCGCCCCCGA TGTCACCGCT GCGGCCGGGG CTGGACCTCG 5360
TGTTCGCCAA CCCGCCCGAC CACTCGGCTC CGCTTGGCGT 5400
GACCAGGCCC AGCGCCCCGC CGCTGCCTCA CGTCGTAGAC 5440
CTACCACAGC TGGGGCCGCG CCGCTAACCG CGGTCGCTCC 5480
GGCCCATGAC ACCCCGCCAG TGCCTGATGT TGACTCCCGC 5520
GGCGCCATCC TGCGCCGGCA GTATAACCTA TCAACATCTC 5560
CCCTCACCTC TTCCGTGGCC ACCGGCACAA ATTTGGTTCT 5600
TTACGCCGCT CCTCTTAGCC CGCTTCTACC CCTCCAGGAC 5640
GGCACCAATA CTCATATAAT GGCTACAGAA GCTTCTAATT 5680
ATGCCCAGTA CCGGGTTGCT CGTGCCACAA TTCGCTACCG 5720
CCCGCTGGTC CCCAACGCTG TTGGTGGCTA CGCTATCTCC 5760
ATTTCGTTCT GGCCACAGAC CACCACCACC CCGACGTCCG 5800
TTGACATGAA TTCAATAACC TCGACGGATG TCCGTATTTT 5840
AGTCCAGCCC GGCATAGCCT CCGAGCTTGT TATTCCAAGT 5880
GAGCGCCTAC ACTATCGCAA CCAAGGTTGG CGCTCTGTTG 5920
AGACCTCCGG GGTGGCGGAG GAGGAGGCCA CCTCTGGTCT 5960
TGTCATGCTC TGCATACATG GCTCACCTGT AAATTCTTAT 6000
ACTAATACAC CCTATACCGG TGCCCTCGGG CTGTTGGACT 6040
TTGCCCTCGA ACTTGAGTTC CGCAACCTCA CCCCCGGTAA 6080
TACCAATACG CGGGTCTCGC GTTACTCCAG CACTGCCCGT 6120
CACCGCCTTC GTCGCGGTGC AGATGGGACT GCCGAGCTCA 6160
CCACCACGGC TGCTACTCGC TTCATGAAGG ACCTCTATTT 6200
TACTAGTACT AATGGTGTTG GTGAGATCGG CCGCGGGATA 6240
GCGCTTACCC TGTTTAACCT TGCTGACACC CTGCTTGGCG 6280
GTCTACCGAC AGAATTGATT TCGTCGGCTG GTGGCCAGCT 6320
GTTCTACTCT CGCCCCGTCG TCTCAGCCAA TGGCGAGCCG 6360
ACTGTTAAGC TGTATACATC TGTGGAGAAT GCTCAGCAGG 6400
ATAAGGGTAT TGCAATCCCG CATGACATCG ACCTCGGGGA 6440
ATCCCGTGTA GTTATTCAGG ATTATGACAA CCAACATGAG 6480
CAGGACCGAC CGACACCTTC CCCAGCCCCA TCGCGTCCTT 6520
TTTCTGTCCT CCGAGCTAAC GATGTGCTTT GGCTTTCTCT 6560
CACCGCTGCC GAGTATGACC AGTCCACTTA CGGCTCTTCG 6600
ACCGGCCCAG TCTATGTCTC TGACTCTGTG ACCTTGGTTA 6640

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ATGTTGCGAC CGGCGCGCAG GCCGTTGCCC GGTCACTCGA   6680
CTGGACCAAG GTCACACTTG ATGGTCGCCC CCTTTCCACC   6720
ATCCAGCAGT ATTCAAAGAC CTTCTTTGTC CTGCCGCTCC   6760
GCGGTAAGCT CTCCTTTTGG GAGGCAGGAA CTACTAAAGC   6800
CGGGTACCCT TATAATTATA ACACCACTGC TAGTGACCAA   6840
CTGCTCGTTG AGAATGCCGC TGGGCATCGG GTTGCTATTT   6880
CCACCTACAC TACTAGCCTG GGTGCTGGCC CCGTCTCTAT   6920
TTCCGCGGTT GCTGTTTTAG CCCCCCACTC TGTGCTAGCA   6960
TTGCTTGAGG ATACCATGGA CTACCCTGCC CGCGCCCATA   7000
CTTTCGATGA CTTCTGCCCG GAGTGCCGCC CCCTTGGCCT   7040
CCAGGGTTGT GCTTTTCAGT CTACTGTCGC TGAGCTTCAG   7080
CGCCTTAAGA TGAAGGTGGG TAAAACTCGG GAGTTATAGT   7120
TTATTTGCTT GTGCCCCCCT TCTTTCTGTT GCTTATTT     7168
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The abbreviations used for the nucleotides are those standardly used in the art.

The sequence in one direction has been designated by convention as the "plus" sequence since it is the protein-encoding strand of RNA viruses and this is the sequence shown above as SEQ ID. NO.:4.

The deduced amino acid sequences of the open reading frames of SAR-55 have SEQ ID NO. 1, SEQ ID NO. 2, and SEQ ID NO. 3. ORF-1 starts at nucleotide 28 of SEQ. ID NO. 4 and extends 5078 nucleotides; ORF-2 starts at nucleotide 5147 of SEQ. ID NO. 4 and extends 1979 nucleotides; and ORF-3 starts at nucleotide 5106 of SEQ. ID NO. 4 and extends 368 nucleotides.

Variations are contemplated in the DNA sequence which will result in a DNA sequence that is capable of directing production of analogs of the ORF-2 protein. By "analogs of the ORF-2 protein" as used throughout the specification and claims is meant a protein having an amino acid sequence substantially identical to a sequence specifically shown herein where one or more of the residues shown in the sequences presented herein have been substituted with a biologically equivalent residue such that

the resultant protein (i.e. the "analog") is antigenic and/or immunogenic. It should be noted that the DNA sequence set forth above represents a preferred embodiment of the present invention. Due to the degeneracy of the genetic code, it is to be understood that numerous choices of nucleotides may be made that will lead to a DNA sequence capable of directing production of the instant ORF proteins or their analogs. As such, DNA sequences which are functionally equivalent to the sequences set forth above or which are functionally equivalent to sequences that would direct production of analogs of the ORF proteins produced pursuant to the amino acid sequence set forth above, are intended to be encompassed within the present invention.

The present invention relates to a method for detecting the hepatitis E virus in biological samples based on selective amplification of hepatitis E gene fragments. Preferably, this method utilizes a pair of single-stranded primers derived from non-homologous regions of opposite strands of a DNA duplex fragment, which in turn is derived from a hepatitis E virus whose genome contains a region homologous to the SAR-55 sequence shown in SEQ ID No.: 4. These primers can be used in a method following the process for amplifying selected nucleic acid sequences as defined in U.S. Patent No. 4,683,202.

The present invention also relates to the use of single-stranded antisense poly-or oligonucleotides derived from sequences homologous to the SAR-55 cDNA to inhibit the expression of hepatitis E genes. These anti-sense poly-or oligonucleotides can be either DNA or RNA. The targeted sequence is typically messenger RNA and more preferably, a signal sequence required for processing or translation of the RNA. The antisense poly-or oligonucleotides can be conjugated to a polycation such as polylysine as disclosed in Lemaitre, M. et al. (1989) Proc Natl Acad Sci USA 84:648-652; and this conjugate can be administered to a mammal in

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an amount sufficient to hybridize to and inhibit the function of the messenger RNA.

The present invention includes a recombinant DNA method for the manufacture of HEV proteins, preferably a protein composed of at least one ORF protein, most preferably at least one ORF-2 protein. The recombinant ORF protein may be composed of one ORF protein or a combination of the same or different ORF proteins. A natural or synthetic nucleic acid sequence may be used to direct production of the HEV proteins. In one embodiment of the invention, the method comprises:

(a) preparation of a nucleic acid sequence capable of directing a host organism to produce a protein of HEV;

(b) cloning the nucleic acid sequence into a vector capable of being transferred into and replicated in a host organism, such vector containing operational elements for the nucleic acid sequence;

(c) transferring the vector containing the nucleic acid and operational elements into a host organism capable of expressing the protein;

(d) culturing the host organism under conditions appropriate for amplification of the vector and expression of the protein; and

(e) harvesting the protein.

In another embodiment of the invention, the method for the recombinant DNA synthesis of a protein encoded by nucleic acids of HEV, preferably a nucleic acid sequence encoding at least one ORF of HEV or a combination of the same or different ORF proteins, most preferably encoding at least one ORF-2 amino acid sequence, comprises:

(a) culturing a transformed or transfected host organism containing a nucleic acid sequence capable of directing the host organism to produce a protein, under conditions such that the protein is produced, said protein exhibiting substantial homology to a native HEV protein

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(over the region of comparison between the two proteins) isolated from HEV having the amino acid sequence according to SEQ ID NO. 1, SEQ ID NO. 2 or SEQ ID NO. 3, or combinations thereof.

In one embodiment, the RNA sequence of the viral genome of HEV strain SAR-55 was isolated and cloned to cDNA as follows. Viral RNA is extracted from a biological sample collected from cynomolgus monkeys infected with SAR-55 and the viral RNA is then reverse transcribed and amplified by polymerase chain reaction using primers complementary to the plus or minus strands of the genome of a strain of HEV from Burma (Tam et al. (1991)) or the SAR-55 genome. The PCR fragments are subcloned into pBR322 or pGEM-32 and the double-stranded PCR fragments were sequenced.

The vectors contemplated for use in the present invention include any vectors into which a nucleic acid sequence as described above can be inserted, along with any preferred or required operational elements, and which vector can then be subsequently transferred into a host organism and replicated in such organism. Preferred vectors are those whose restriction sites have been well documented and which contain the operational elements preferred or required for transcription of the nucleic acid sequence.

The "operational elements" as discussed herein include at least one promoter, at least one terminator codon, and any other DNA sequences necessary or preferred for appropriate transcription and subsequent translation of the vector nucleic acid. In particular, it is contemplated that such vectors will contain at least one origin of replication recognized by the host organism along with at least one selectable marker and at least one promoter sequence capable of initiating transcription of the nucleic acid sequence.

In construction of the cloning vector of the present invention, it should additionally be noted that multiple copies of the nucleic acid sequence and its

attendant operational elements may be inserted into each vector. In such an embodiment, the host organism would produce greater amounts per vector of the desired HEV protein. The number of multiple copies of the DNA sequence (either a single sequence or two distinct sequences), which may be inserted into the vector is limited only by the ability of the resultant vector due to its size, to be transferred into and replicated and transcribed in an appropriate host microorganism.

In another embodiment, restriction digest fragments containing a coding sequence for HEV proteins can be inserted into a suitable expression vector that functions in prokaryotic or eukaryotic cells. By suitable is meant that the vector is capable of carrying and expressing a complete nucleic acid sequence coding for HEV proteins, preferably at least one ORF protein. Preferred expression vectors are those that function in a eukaryotic cell. Examples of such vectors include but are not limited to vectors useful for expression in yeast (e.g. pPIC9 vector-Invitrogen) vaccinia virus vectors, adenovirus or herpesviruses, preferably baculovirus transfer vectors. Preferred vectors are p63-2, which contains the complete ORF-2 gene, and P59-4, which contains the complete ORF-3 and ORF-2 genes. These vectors were deposited with the American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD 20852, ~~USA~~ 10801 University Boulevard, Manassas, VA 20110-2209 USA on September 10, 1992 and have accession numbers 75299 (P63-2) and 75300 (P59-4). More preferred vectors are bHEV ORF-2 5'tr, which encodes amino acids 112-660 of ORF-2, bHEV ORF-2 5'-3'tr, which encodes amino acids 112-607 of ORF-2, and a baculovirus vector which encodes amino acids 112-578 of HEV ORF2. Example 1 illustrates the cloning of the ORF-2 gene into pBlueBac to produce p63-2. This method includes digesting the genome of HEV strain SAR-55 with the restriction enzymes NruI and BglII, inserting a polylinker containing BlnI and BglII sites into the unique NheI site of

the vector and inserting the NruI-BglII ORF-2 fragment in BlnI-BglII pBlueBac using an adapter.

In yet another embodiment, the selected recombinant expression vector may then be transfected into a suitable eukaryotic cell system for purposes of expressing the recombinant protein. Such eukaryotic cell systems include, but are not limited to, yeast, and cell lines such as HeLa, MRC-5, CV-1, HuH7 or HepG2. One preferred eukaryotic cell system is Sf9 insect cells. One preferred method involves use of the baculovirus expression vectors and where the insect cell line Sf9.

The expressed recombinant protein may be detected by methods known in the art which include Coomassie blue staining and Western blotting using sera containing anti-HEV antibody as shown in Example 2. Another method is the detection of virus-like particles by immunoelectron microscopy as shown in Example 3.

In a further embodiment, the recombinant protein expressed by the SF9 cells can be obtained as a crude lysate or it can be purified by standard protein purification procedures known in the art which may include differential precipitation, molecular sieve chromatography, ion-exchange chromatography, isoelectric focusing, gel electrophoresis, affinity, and immunoaffinity chromatography and the like. In the case of immunoaffinity chromatography, the recombinant protein may be purified by passage through a column containing a resin which has bound thereto antibodies specific for the ORF protein. An example of protocols for the purification of recombinantly expressed HEV ORF2 protein from clarified baculovirus-infected cell lysates and supernatant media respectively are described in Example 16.

In another embodiment, the expressed recombinant proteins of this invention can be used in immunoassays for diagnosing or prognosing hepatitis E in a mammal including but not limited to humans, chimpanzees, Old World monkeys, New World monkeys, other primates and the like. In a

preferred embodiment, the immunoassay is useful in diagnosing hepatitis E infection in humans. Immunoassays using the HEV proteins, particularly the ORF proteins, and especially ORF 2 proteins, provide a highly specific, sensitive and reproducible method for diagnosing HEV infections, in contrast to immunoassays which utilize partial ORF proteins.

Immunoassays of the present invention may be a radioimmunoassay, Western blot assay, immunofluorescent assay, enzyme immunoassay, chemiluminescent assay, immunohistochemical assay and the like. Standard techniques known in the art for ELISA are described in Methods in Immunodiagnosis, 2nd Edition, Rose and Bigazzi, eds., John Wiley and Sons, 1980 and Campbell et al., Methods of Immunology, W.A. Benjamin, Inc., 1964, both of which are incorporated herein by reference. Such assays may be a direct, indirect, competitive, or noncompetitive immunoassay as described in the art. (Oellerich, M. 1984. J.Clin. Chem. Clin. BioChem. 22: 895-904) Biological samples appropriate for such detection assays include, but are not limited to, tissue biopsy extracts, whole blood, plasma, serum, cerebrospinal fluid, pleural fluid, urine and the like.

In one embodiment, test serum is reacted with a solid phase reagent having surface-bound recombinant HEV protein as an antigen, preferably an ORF protein or combination of different ORF proteins such as ORF-2 and ORF-3, ORF-1 and ORF-3 and the like. Most preferably, the HEV protein is a protein consisting essentially of amino acids 112-607 of HEV ORF2. The solid surface reagent can be prepared by known techniques for attaching protein to solid support material. These attachment methods include non-specific adsorption of the protein to the support or covalent attachment of the protein to a reactive group on the support. After reaction of the antigen with anti-HEV antibody, unbound serum components are removed by washing and the antigen-antibody complex is reacted with a secondary antibody such as labelled anti-human antibody. The label

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may be an enzyme which is detected by incubating the solid support in the presence of a suitable fluorimetric or colorimetric reagent. Other detectable labels may also be used, such as radiolabels or colloidal gold, and the like.

In a preferred embodiment, the protein expressed by the recombinant baculovirus vector containing the ORF-2 sequence of SAR-55 which encodes amino acids 112-607 of HEV ORF2 is used as a specific binding agent to detect anti-HEV antibodies, preferably IgG or IgM antibodies. Example 10 shows the results of an ELISA in which the solid phase reagent has the recombinant 55 kilodalton protein consisting of amino acids 112-607 as the surface antigen. This protein is capable of detecting antibodies produced in response to different strains of HEV but does not detect antibodies produced in response to Hepatitis A, B, C or D.

The HEV protein and analogs may be prepared in the form of a kit, alone, or in combinations with other reagents such as secondary antibodies, for use in immunoassays.

The recombinant HEV proteins, preferably an ORF protein or combination of ORF proteins, more preferably an ORF-2 protein and substantially homologous proteins and analogs of the invention can be used as a vaccine to protect mammals against challenge with Hepatitis E. The vaccine, which acts as an immunogen, may be a cell, cell lysate from cells transfected with a recombinant expression vector or a culture supernatant containing the expressed protein. Alternatively, the immunogen is a partially or substantially purified recombinant protein. While it is possible for the immunogen to be administered in a pure or substantially pure form, it is preferable to present it as a pharmaceutical composition, formulation or preparation.

The formulations of the present invention, both for veterinary and for human use, comprise an immunogen as described above, together with one or more pharmaceutically acceptable carriers and optionally other therapeutic ingredients. The carrier(s) must be "acceptable" in the sense of

being compatible with the other ingredients of the formulation and not deleterious to the recipient thereof. The formulations may conveniently be presented in unit dosage form and may be prepared by any method well-known in the pharmaceutical art.

All methods include the step of bringing into association the active ingredient with the carrier which constitutes one or more accessory ingredients. In general, the formulations are prepared by uniformly and intimately bringing into association the active ingredient with liquid carriers or finely divided solid carriers or both, and then, if necessary, shaping the product into the desired formulation.

Formulations suitable for intravenous, intramuscular, subcutaneous, or intraperitoneal administration conveniently comprise sterile aqueous solutions of the active ingredient with solutions which are preferably isotonic with the blood of the recipient. Such formulations may be conveniently prepared by dissolving solid active ingredient in water containing physiologically compatible substances such as sodium chloride (e.g. 0.1-2.0M), glycine, and the like, and having a buffered pH compatible with physiological conditions to produce an aqueous solution, and rendering said solution sterile. These may be present in unit or multi-dose containers, for example, sealed ampoules or vials.

The formulations of the present invention may incorporate a stabilizer. Illustrative stabilizers are polyethylene glycol, proteins, saccharides, amino acids, inorganic acids, and organic acids which may be used either on their own or as admixtures. These stabilizers are preferably incorporated in an amount of 0.11-10,000 parts by weight per part by weight of immunogen. If two or more stabilizers are to be used, their total amount is preferably within the range specified above. These stabilizers are used in aqueous solutions at the appropriate concentration

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and pH. The specific osmotic pressure of such aqueous solutions is generally in the range of 0.1-3.0 osmoles, preferably in the range of 0.8-1.2. The pH of the aqueous solution is adjusted to be within the range of 5.0-9.0, preferably within the range of 6-8. In formulating the immunogen of the present invention, anti-adsorption agent may be used.

Additional pharmaceutical methods may be employed to control the duration of action. Controlled release preparations may be achieved through the use of polymer to complex or absorb the proteins or their derivatives. The controlled delivery may be exercised by selecting appropriate macromolecules (for example polyester, polyamino acids, polyvinyl, pyrrolidone, ethylenevinylacetate, methylcellulose, carboxymethylcellulose, or protamine sulfate) and the concentration of macromolecules as well as the methods of incorporation in order to control release. Another possible method to control the duration of action by controlled-release preparations is to incorporate the proteins, protein analogs or their functional derivatives, into particles of a polymeric material such as polyesters, polyamino acids, hydrogels, poly(lactic acid) or ethylene vinylacetate copolymers. Alternatively, instead of incorporating these agents into polymeric particles, it is possible to entrap these materials in microcapsules prepared, for example, by coacervation techniques or by interfacial polymerization, for example, hydroxymethylcellulose or gelatin-microcapsules and poly(methylmethacylate) microcapsules, respectively, or in colloidal drug delivery systems, for example, liposomes, albumin microspheres, microemulsions, nanoparticles, and nanocapsules or in macroemulsions.

When oral preparations are desired, the compositions may be combined with typical carriers, such as lactose, sucrose, starch, talc, magnesium stearate, crystalline cellulose, methyl cellulose, carboxymethyl

cellulose, glycerin, sodium alginate or gum arabic among others.

The proteins of the present invention may be supplied in the form of a kit, alone or in the form of a pharmaceutical composition as described above.

Vaccination can be conducted by conventional methods. For example, the immunogen can be used in a suitable diluent such as saline or water, or complete or incomplete adjuvants. Further, the immunogen may or may not be bound to a carrier to make the protein immunogenic. Examples of such carrier molecules include but are not limited to bovine serum albumin (BSA), keyhole limpet hemocyanin (KLH), tetanus toxoid, and the like. The immunogen can be administered by any route appropriate for antibody production such as intravenous, intraperitoneal, intramuscular, subcutaneous, and the like. The immunogen may be administered once or at periodic intervals until a significant titer of anti-HEV antibody is produced. The antibody may be detected in the serum using an immunoassay.

In yet another embodiment, the immunogen may be nucleic acid sequence capable of directing host organism synthesis of an HEV ORF protein. Such nucleic acid sequence may be inserted into a suitable expression vector by methods known to those skilled in the art. Expression vectors suitable for producing high efficiency gene transfer <u>in vivo</u> include, but are not limited to, retroviral, adenoviral and vaccinia viral vectors. Operational elements of such expression vectors are disclosed previously in the present specification and are known to one skilled in the art. Such expression vectors can be administered intravenously, intramuscularly, subcutaneously, intraperitoneally or orally.

In an alternative embodiment, direct gene transfer may be accomplished via intramuscular injection of, for example, plasmid-based eukaryotic expression vectors containing a nucleic acid sequence capable of directing host

organism synthesis of HEV ORF protein(s). Such an approach has previously been utilized to produce the hepatitis B surface antigen in vivo and resulted in an antibody response to the surface antigen (Davis, H.L. et al. (1993) Human Molecular Genetics, 2:1847-1851; see also Davis et al. (1993) Human Gene Therapy, 4:151-159 and 733-740) and Davis, H.L. et al., Proc Natl Acad Sci USA (1996) 93:7213-7218).

When the immunogen is a partially or substantially purified recombinant HEV ORF protein, dosages effective to elicit a protective antibody response against HEV range from about 0.1 μg to about 100 μg. A more preferred range is from about 0.5 μg to about 70 μg and a most preferred range is from about 10 μg to about 50 μg.

Dosages of HEV-ORF protein - encoding nucleic acid sequence effective to elicit a protective antibody response against HEV range from about 1 to about 5000 μg; a more preferred range being about 300 to about 2000 μg.

The expression vectors containing a nucleic acid sequence capable of directing host organism synthesis of an HEV ORF protein(s) may be supplied in the form of a kit, alone or in the form of a pharmaceutical composition as described above.

The administration of the immunogen of the present invention may be for either a prophylactic or therapeutic purpose. When provided prophylactically, the immunogen is provided in advance of any exposure to HEV or in advance of any symptom due to HEV infection. The prophylactic administration of the immunogen serves to prevent or attenuate any subsequent infection of HEV in a mammal. When provided therapeutically, the immunogen is provided at (or shortly after) the onset of the infection or at the onset of any symptom of infection or disease caused by HEV. The therapeutic administration of the immunogen serves to attenuate the infection or disease.

A preferred embodiment is a vaccine prepared using recombinant ORF-2 protein expressed by the ORF-2 sequence of

HEV strain SAR-55 and equivalents thereof. Since the recombinant ORF-2 protein has been demonstrated to provide protection against challenge with heterologous or homologous HEV strains, their utility in protecting against a variety of HEV strains is indicated.

In addition to use as a vaccine, the compositions can be used to prepare antibodies to HEV virus-like particles. The antibodies can be used directly as antiviral agents. To prepare antibodies, a host animal is immunized using the virus particles or, as appropriate, non-particle antigens native to the virus particle are bound to a carrier as described above for vaccines. The host serum or plasma is collected following an appropriate time interval to provide a composition comprising antibodies reactive with the virus particle. The gamma globulin fraction or the IgG antibodies can be obtained, for example, by use of saturated ammonium sulfate or DEAE Sephadex, or other techniques known to those skilled in the art. The antibodies are substantially free of many of the adverse side effects which may be associated with other anti-viral agents such as drugs.

The antibody compositions can be made even more compatible with the host system by minimizing potential adverse immune system responses. This is accomplished by removing all or a portion of the Fc portion of a foreign species antibody or using an antibody of the same species as the host animal, for example, the use of antibodies from human/human hybridomas. Humanized antibodies (i.e., nonimmunogenic in a human) may be produced, for example, by replacing an immunogenic portion of an antibody with a corresponding, but nonimmunogenic portion (i.e., chimeric antibodies). Such chimeric antibodies may contain the reactive or antigen binding portion of an antibody from one species and the Fc portion of an antibody (nonimmunogenic) from a different species. Examples of chimeric antibodies, include but are not limited to, non-human mammal-human

chimeras, rodent-human chimeras, murine-human and rat-human chimeras (Robinson et al., International Patent Application 184,187; Taniguchi M., European Patent Application 171,496; Morrison et al., European Patent Application 173,494; Neuberger et al., PCT Application WO 86/01533; Cabilly et al., 1987 Proc. Natl. Acad. Sci. USA 84:3439; Nishimura et al., 1987 Canc. Res. 47:999; Wood et al., 1985 Nature 314:446; Shaw et al., 1988 J. Natl. Cancer Inst. 80: 15553, all incorporated herein by reference).

General reviews of "humanized" chimeric antibodies are provided by Morrison S., 1985 Science 229:1202 and by Oi et al., 1986 BioTechniques 4:214.

Suitable "humanized" antibodies can be alternatively produced by CDR or CEA substitution (Jones et al., 1986 Nature 321:552; Verhoeyan et al., 1988 Science 239:1534; Biedleret al. 1988 J. Immunol. 141:4053, all incorporated herein by reference).

The antibodies or antigen binding fragments may also be produced by genetic engineering. The technology for expression of both heavy and light chain genes in E. coli is the subject of the PCT patent applications; publication number WO 901443, WO901443, and WO 9014424 and in Huse et al., 1989 Science 246:1275-1281.

The antibodies can also be used as a means of enhancing the immune response. The antibodies can be administered in amounts similar to those used for other therapeutic administrations of antibody. For example, pooled gamma globulin is administered at 0.02-0.1 ml/lb body weight during the early incubation period of other viral diseases such as rabies, measles and hepatitis B to interfere with viral entry into cells. Thus, antibodies reactive with the HEV virus particle can be passively administered alone or in conjunction with another anti-viral agent to a host infected with an HEV to enhance the effectiveness of an antiviral drug.

Alternatively, anti-HEV antibodies can be induced by administering anti-idiotype antibodies as immunogens. Conveniently, a purified anti-HEV antibody preparation prepared as described above is used to induce anti-idiotype antibody in a host animal. The composition is administered to the host animal in a suitable diluent. Following administration, usually repeated administration, the host produces anti-idiotype antibody. To eliminate an immunogenic response to the Fc region, antibodies produced by the same species as the host animal can be used or the FC region of the administered antibodies can be removed. Following induction of anti-idiotype antibody in the host animal, serum or plasma is removed to provide an antibody composition. The composition can be purified as described above for anti-HEV antibodies, or by affinity chromatography using anti-HEV antibodies bound to the affinity matrix. The anti-idiotype antibodies produced are similar in conformation to the authentic HEV-antigen and may be used to prepare an HEV vaccine rather than using an HEV particle antigen.

When used as a means of inducing antivirus antibodies in an animal, the manner of injecting the antibody is the same as for vaccination purposes, namely intramuscularly, intraperitoneally, subcutaneously or the like in an effective concentration in a physiologically suitable diluent with or without adjuvant. One or more booster injections may be desirable.

The HEV derived proteins of the invention are also intended for use in producing antiserum designed for pre- or post-exposure prophylaxis. Here an HEV protein, or mixture of proteins is formulated with a suitable adjuvant and administered by injection to human volunteers, according to known methods for producing human antisera. Antibody response to the injected proteins is monitored, during a several-week period following immunization, by periodic

serum sampling to detect the presence of anti-HEV serum antibodies, using an immunoassay as described herein.

The antiserum from immunized individuals may be administered as a pre-exposure prophylactic measure for individuals who are at risk of contracting infection. The antiserum is also useful in treating an individual post-exposure, analogous to the use of high titer antiserum against hepatitis B virus for post-exposure prophylaxis. Of course, those of skill in the art would readily understand that immune globulin (HEV immune globulin) purified from the antiserum of immunized individuals using standard techniques may be used as a pre-exposure prophylactic measure or in treating individuals post-exposure.

For both in vivo use of antibodies to HEV virus-like particles and proteins and anti-idiotype antibodies and diagnostic use, it may be preferable to use monoclonal antibodies. Monoclonal anti-virus particle antibodies or anti-idiotype antibodies can be produced as follows. The splenocytes or lymphocytes from an immunized animal are removed and immortalized or used to prepare hybridomas by methods known to those skilled in the art. (Goding, J.W. 1983. Monoclonal Antibodies: Principles and Practice, Pladermic Press, Inc., NY, NY, pp. 56-97). To produce a human-human hybridoma, a human lymphocyte donor is selected. A donor known to be infected with HEV (where infection has been shown for example by the presence of anti-virus antibodies in the blood or by virus culture) may serve as a suitable lymphocyte donor. Lymphocytes can be isolated from a peripheral blood sample or spleen cells may be used if the donor is subject to splenectomy. Epstein-Barr virus (EBV) can be used to immortalize human lymphocytes or a human fusion partner can be used to produce human-human hybridomas. Primary in vitro immunization with peptides can also be used in the generation of human monoclonal antibodies.

Antibodies secreted by the immortalized cells are screened to determine the clones that secrete antibodies of the desired specificity. For monoclonal anti-virus particle antibodies, the antibodies must bind to HEV virus particles. For monoclonal anti-idiotype antibodies, the antibodies must bind to anti-virus particle antibodies. Cells producing antibodies of the desired specificity are selected.

In another embodiment, monoclonal antibodies are derived by harvesting messenger RNA encoding V-genes of B cells from humans or chimpanzees who are immune to the antigen of interest. The messenger RNAs encoding the heavy and light chains of immunoglobins are amplified by reverse transcriptase-polymerase chain reaction, combined at random and cloned into filamentous phage for display. The phage are then selected for carriage of antibodies of interest by "panning" on the antigen of choice, which is attached to a solid phase. The recovered phage that display the combining sites of antibodies homologous to the antigen are amplified and the antibody genes they carry are assembled to encode complete antibody molecules. Such antibodies, specific to the antigen of interest, are expressed in *E. coli*, purified and utilized as described above for human monoclonal antibodies. Generation of human monoclonal antibodies from combinational libraries is described, for example, in Hoogenboom, H.R., and Winter, G., (1992) *Journal of Molecular Biology*, volume 227, pages 381-388, and in Chanock, R.M., et al., (1993) *Infectious Agents and Disease*, volume 2, pages 118-131.

The above described antibodies and antigen binding fragments thereof may be supplied in kit form alone, or as a pharmaceutical composition for in vivo use. The antibodies may be used for therapeutic uses, diagnostic use in immunoassays or as an immunoaffinity agent to purify ORF proteins as described herein.

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Material

The materials used in the Examples were as follows:

Primates. Chimpanzee (Chimp) (*Pan troglodytes*). Old world monkeys: cynomolgus monkeys (Cyno) (*Macaca fascicularis*), rhesus monkeys (Rhesus) (*M. mulatta*), pigtail monkeys (PT) (M. nemestrina), and African green monkeys (AGM) (*Cercopithecus aethiops*). New World monkeys: mustached tamarins (Tam) (*Saguinus mystax*), squirrel monkeys (SQM) (Saimiri sciureus) and owl monkeys (OWL) (*Aotus trivigatus*). Primates were housed singly under conditions of biohazard containment. The housing, maintenance and care of the animals met or exceeded all requirements for primate husbandry.

Most animals were inoculated intravenously with HEV, strain SAR-55 contained in 0.5 ml of stool suspension diluted in fetal calf serum as described in Tsarev, S.A. et al. (1992), Proc. Natl. Acad. Sci USA, 89:559-563; and Tsarev, S.A. et al. (1993), J. Infect. Dis. (167:1302-1306). Chimp-1313 and 1310 were inoculated with a pool of stools collected from 7 Pakistani hepatitis E patients.

Serum samples were collected approximately twice a week before and after inoculation. Levels of the liver enzymes serum alanine amino transferase (ALT), isocitrate dehydrogenase (ICD), and gamma glutamyl transferase (GGT) were assayed with commercially available tests (Medpath Inc., Rockville, MD). Serologic tests were performed as described above.

EXAMPLE 1

Identification of the DNA Sequence of the Genome of HEV Strain SAR-55.

Preparation of Virus RNA Template for PCR. Bile from an HEV-infected cynomolgus monkey (10 µl), 20% (wt/vol) SDS (to a final concentration of 1%), proteinase K (10 mg/ml; to a final concentration of 1 mg/ml), 1 µl of tRNA (10 mg/ml), and 3 µl of 0.5 M EDTA were mixed in a final

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volume of 250 μl and incubated for 30 min. at 55°C. Total nucleic acids were extracted from bile twice with phenol/chloroform, 1:1 (vol/vol), at 65°C and once with chloroform, then precipitated by ethanol, washed with 95% ethanol, and used for RT-PCR. RT-PCR amplification of HEV RNA from feces and especially from sera was more efficient when RNA was more extensively purified. Serum (100 μl) or a 10% fecal suspension (200 μl) was treated as above with proteinase K. After a 30-min incubation, 300 μl of CHAOS buffer (4.2 M guanidine thiocyanate/0.5 *N*-lauroylsarocosine/0.025 M Tris-HCL, pH 8.0) was added. Nucleic acids were extracted twice with phenol/chloroform at 65°C followed by chloroform extraction at room temperature. Then 7.5 M ammonium acetate (225 μl) was added to the upper phase and nucleic acids were precipitated with 0.68 ml of 2-propanol. The pellet was dissolved in 300 ul CHAOS buffer and 100 ul of H_2O was added. Chloroform extraction and 2-propanol precipitation were repeated. Nucleic acids were dissolved in water, precipitated with ethanol, washed with 95% ethanol, and used for RT-PCR.

Primers. Ninety-four primers, 21-40 nucleotides (nt) long, and complementary to plus or minus strands of the genome of a strain of HEV from Burma (BUR-121) (Tam, A.W. et al. (1991), Virology, 185:120-131) or the SAR-55 genome were synthesized using an Applied Biosystems model 391 DNA synthesizer.

The sequences of these 94 primers are shown below starting with SEQ. ID NO. 5 and continuing to SEQ. ID NO. 98:

HEV Primer List

Primer	ORF Region	Sequence	
D 3042 B	1	ACATTTGAATTCACAGACAT TGTGC	(SEQ. ID. NO. 5)
R 3043 B	1	ACACAGATCTGAGCTACATT CGTGAG	(SEQ. ID. NO. 6)

	D	3044	B	1	AAAGGGATCCATGGTGTTTG AGAATG (SEQ. ID. NO. 7)
	R	3045	B	1	ACTCACTGCAGAGCACTATC GAATC (SEQ. ID. NO. 8)
	R	261	S	1	CGGTAAACTGGTACTGCACA AC (SEQ. ID. NO. 9)
	D	260	S	1	AAGTCCCGCTCTATTACCCA AG (SEQ. ID. NO. 10)
	D	259	S	1	ACCCACGGGTGTTGGTTTTT G (SEQ. ID. NO. 11)
	R	255	S	1	TTCTTGGGGCAGGTAGAGAA G (SEQ. ID. NO. 12)
	R	254	S	2	TTATTGAATTCATGTCAACG GACGTC (SEQ. ID. NO. 13)

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	D	242	S	1	AATAATTCATGCCGTCGCTCC	(SEQ. ID. NO. 14)
	R	241	S	1	AAGCTCAGGAAGGTACAACTC	(SEQ. ID. NO. 15)
	R	231	S	1	AAATCGATGGCTGGGATCTGATTC	(SEQ. ID. NO. 16)
	R	230	S	1	GAGGCATTGTAGAGCTTTGTG	(SEQ. ID. NO. 17)
	D	229	S	1	GATGTTGCACGGACAGCAAATC	(SEQ. ID. NO. 18)
	D	228	S	1	ATCTCCGATGCAATCGTTAATAAC	(SEQ. ID. NO. 19)
	D	227	B	1	TAATCCATTCTGTGGCGAGAG	(SEQ. ID. NO. 20)
	R	218	B	2	AAGTGTGACCTTGGTCCAGTC	(SEQ. ID. NO. 21)
	D	217	B	2	TTGCTCGTGCCACAATTCGCTAC	(SEQ. ID. NO. 22)
	D	211	B	1	CATTTCACTGAGTCAGTGAAG	(SEQ. ID. NO. 23)
	D	202	B	2	TAATTATAACACCACTGCTAG	(SEQ. ID. NO. 24)
	R	201	B	2	GATTGCAATACCCTTATCCTG	(SEQ. ID. NO. 25)
	R	200	S	1	ATTAAACCTGTATAGGGCAGAAC	(SEQ. ID. NO. 26)
	R	199	S	1	AAGTTCGATAGCCAGATTTGC	(SEQ. ID. NO. 27)
	R	198	S	2	TCATGTTGGTTGTCATAATCC	(SEQ. ID. NO. 28)
	R	193	B	1	GATGACGCACTTCTCAGTGTG	(SEQ. ID. NO. 29)
	R	192	B	1	AGAACAACGAACGGAGAAC	(SEQ. ID. NO. 30)
	D	191	B	1	AGATCCCAGCCATCGACTTTG	(SEQ. ID. NO. 31)

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	R	190	S	2	TAGTAGTGTAGGTGGAAATAG	(SEQ. ID. NO. 32)
	D	189	B	2	GTGTGGTTATTCAGGATTATG	(SEQ. ID. NO. 33)
	D	188	B	2	ACTCTGTGACCTTGGTTAATG	(SEQ. ID. NO. 34)
	R	187	S	2	AACTCAAGTTCGAGGGCAAAG	(SEQ. ID. NO. 35)
	D	186	S	2	CGCTTACCCTGTTTAACCTTG	(SEQ. ID. NO. 36)
	D	185	B	2,3	ATCCCCTATATTCATCCAACCAAC	(SEQ. ID. NO. 37)
	D	184	S	2,3	CTCCTCATGTTTCTGCCTATG	(SEQ. ID. NO. 38)
	R	181	S	2	GCCAGAACGAAATGGAGATAGC	(SEQ. ID. NO. 39)
	R	180	B	1	CTCAGACATAAAACCTAAGTC	(SEQ. ID. NO. 40)
	D	179	S	1	TGCCCTATACAGGTTTAATCG	(SEQ. ID. NO. 41)
	D	178	B	1	ACCGGCATATACCAGGTGC	(SEQ. ID. NO. 42)
	D	177	B	2	ACATGGCTCACTCGTAAATTC	(SEQ. ID. NO. 43)
	R	174	B	1	AACATTAGACGCGTTAACGAG	(SEQ. ID. NO. 44)
	D	173	S	1	CTCTTTTGATGCCAGTCAGAG	(SEQ. ID. NO. 45)
	D	172	B	1	ACCTACCCGGATGGCTCTAAGG	(SEQ. ID. NO. 46)
	R	166	B	2	TATGGGAATTCGTGCCGTCCTGAAG (EcoRI)	(SEQ. ID. NO. 47)
	R	143	B	1	AGTGGGAGCAGTATACCAGCG	(SEQ. ID. NO. 48)
	D	141	B	1	CTGCTATTGAGCAGGCTGCTC	(SEQ. ID. NO. 49)

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R	142	S	1	GGGCCATTAGTCTCTAAAAC C	(SEQ. ID. NO. 50)
D	135	B	1	GAGGTTTTCTGGAATCATC	(SEQ. ID. NO. 51)
R	134	B	1	GCATAGGTGAGACTG	(SEQ. ID. NO. 52)
R	133	B	1	AGTTACAGCCAGAAAACC	(SEQ. ID. NO. 53)
D	132	S	2,3	CCATGGATCCTCGGCCTATT TTGCTGTTGCTCC (Bam HI)	(SEQ. ID. NO. 54)
D	131	B	5'NC	AGGCAGACCACATATGTG	(SEQ. ID. NO. 55)
R	119	B	1	GGTGCACTCCTGACCAAGCC	(SEQ. ID. NO. 56)
D	118	B	1	ATTGGCTGCCACTTTGTTC	(SEQ. ID. NO. 57)
R	117	B	1	ACCCTCATACGTCACCACAA C	(SEQ. ID. NO. 58)
R	116	B	1	GCGGTGGACCACATTAGGAT TATC	(SEQ. ID. NO. 59)
D	115	B	1	CATGATATGTCACCATCTG	(SEQ. ID. NO. 60)
D	114	B	1	GTCATCCATAACGAGCTGG	(SEQ. ID. NO. 61)
R	112	B	2	AGCGGAATTCGAGGGGCGGC ATAAAGAACCAGG (EcoRI)	(SEQ. ID. NO. 62)
R	111	B	2	GCGCTGAATTCGGATCACAA GCTCAGAGGCTATGCC (EcoRI)	(SEQ. ID. NO. 63)
D	110	B	2	GTATAACGGATCCACATCTC CCCTTACCTC (Bam HI)	(SEQ. ID. NO. 64)
D	109	B	2	TAACCTGGATCCTTATGCCG CCCCTCTTAG (Bam HI)	(SEQ. ID. NO. 65)
D	108	B	1	AAATTGGATCCTGTGTCGGG TGGAATGAATAACATGTC (BamHI)	(SEQ. ID. NO. 66)
R	107	B	1	ATCGGCAGATCTGATAGAGC GGGGACTTGCCGGATCC	(SEQ. ID. NO. 67)
D	101	B	2	TACCCTGCCCGCGCCCATAC TTTTGATG	(SEQ. ID. NO. 68)
R	100	B	1	GGCTGAGATCTGGTTCGGGT CGCCAAGAAGGTG (Bgl II)	(SEQ. ID. NO. 69)

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	R	99	B	2	TACAGATCTATACAACTTAA CAGTCGG (Bgl II) (SEQ. ID. NO. 70)
	R	98	B	2	GCGGCAGATCTCACCGACAC CATTAGTAC (Bgl II) (SEQ. ID. NO. 71)
	D	97	S	1	CCGTCGGATCCCAGGGGCTG CTGTCCTG (Bam HI) (SEQ. ID. NO. 72)
	R	96	B	2	AAAGGAATTCAAGACCAGAG GTAGCCTCCTC (EcoRI) (SEQ. ID. NO. 73)
	D	95	B	2	GTTGATATGAATTCAATAAC CTCGACGG (SEQ. ID. NO. 74)
	R	94	B	3'NC	TTTGGATCCTCAGGGAGCGC GGAACGCAGAAATGAG (BamHI) (SEQ. ID. NO. 75)
	D	90	B	2	TCACTCGTGAATTCCTATAC TAATAC (EcoRI) (SEQ. ID. NO. 76)
	R	89	B	3'NC	TTTGGATCCTCAGGGAGCGC GGAACGCAGAAATG (BamHI) (SEQ. ID. NO. 77)
	R	88	B	1	TGATAGAGCGGGACTTGCCG GATCC (BamHI) (SEQ. ID. NO. 78)
	R	87	B	1	TTGCATTAGGTTAATGAGGA TCTC (SEQ. ID. NO. 79)
	D	86	B	1	ACCTGCTTCCTTCAGCCTGC AGAAG (SEQ. ID. NO. 80)
	R	81	B	1	GCGGTGGATCCGCTCCCAGG CGTCAAAAC (BamHI) (SEQ. ID. NO. 81)
	D	80	B	1	GGGCGGATCGAATTCGAGAC CCTTCTTGG (EcoRI) (SEQ. ID. NO. 82)
	R	79	B	1	AGGATGGATCCATAAGTTAC CGATCAG (BamHI) (SEQ. ID. NO. 83)
	D	78	B	1	GGCTGGAATTCCTCTGAGGA CGCCCTCAC (EcoRI) (SEQ. ID. NO. 84)
	R	77	B	1	GCCGAAGATCTATCGGACAT AGACCTC (Bgl II) (SEQ. ID. NO. 85)
	R	76	B	2	CAGACGACGGATCCCCTTGG ATATAGCCTG (BamHI) (SEQ. ID. NO. 86)

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D	75	B	5'NC	GGCCGAATTCAGGCAGACCA CATATGTGGTCGATGCCATG (EcoRI)	(SEQ. ID. NO. 87)
D	72	B	1	GCAGGTGTGCCTGGATCCGG CAAGT (BamHI)	(SEQ. ID. NO. 88)
R	71	B	1	GTTAGAATTCCGGCCCAGCT GTGGTAGGTC (EcoRI)	(SEQ. ID. NO. 89)
D	63	B	1	CCGTCCGATTGGTCTGTATG CAGG	(SEQ. ID. NO. 90)
D	61	B	1	TACCAGTTTACTGCAGGTGT GC	(SEQ. ID. NO. 91)
D	60	B	1	CAAGCCGATGTGGACGTTGT CG	(SEQ. ID. NO. 92)
R	59	B	2,3	GGCGCTGGGCCTGGTCACGC CAAG	(SEQ. ID. NO. 93)
D	50	B	1	GCAGAAACTAGTGTTGACCC AG	(SEQ. ID. NO. 94)
R	49	B	2	TAGGTCTACGACGTGAGGCA AC	(SEQ. ID. NO. 95)
R	48	B	1	TACAATCTTTCAGGAAGAAG G	(SEQ. ID. NO. 96)
R	47	B	1	CCCACACTCCTCCATAATAG C	(SEQ. ID. NO. 97)
D	46	B	1	GATAGTGCTTTGCAGTGAGT ACCG	(SEQ. ID. NO. 98)

The abbreviations to the left of the sequences represent the following: R and D refer to reverse and forward primers, respectively; B and S refer to sequences derived from the Burma-121 Strain of Hepatitis E and the SAR-55 Strain of Hepatitis E, respectively; 5'NC and 3'NC refer to 5 prime and 3 prime non-coding regions of the HEV genome, respectively; and 1, 2 and 3 refer to sequence derived from open reading frames 1, 2 or 3, respectively. The symbol () to the right of some sequences shown indicates insertion of an artificial restriction site into these sequences.

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For cloning of PCR fragments, *Eco*RI, *Bam*HI, or *Bgl*II restriction sites preceded by 3-7 nt were added to the 5′ end of primers.

RT-PCR. The usual 100-μl RT-PCR mixture contained template, 10 mM Tris-HCL (ph 8.4), 50 mM KCl, 2.5 mM $MgCl_2$, all four dNTPs (each at 0.2 mM), 50 pmol of direct primer, 50 pmol of reverse primer, 40 units of RNasin (Promega), 16 units of avian myeloblastosis virus reverse transcriptase (Promega), 4 units of AmpliTaq (Cetus), under 100 μl of light mineral oil. The mixture was incubated 1 h at 42°C and then amplified by 35 PCR cycles; 1 min at 94°C, 1 min at 45°C, and 1 min at 72°C. The PCR products were analyzed on 1% agarose gels.

Cloning of PCR Fragments. PCR fragments containing restriction sites at the ends were digested with *Eco*RI and *Bam*HI or *Eco*RI and *Bgl*II restriction enzymes and cloned in *Eco*RI/*Bam*HI-digested pBR322 or pGEM-3Z (Promega). Alternatively, PCR fragments were cloned into pCR1000 (Invitrogen) using the TA cloning kit (Invitrogen).

Sequencing of PCR Fragments and Plasmids. PCR fragments were excised from 1% agarose gels and purified by Geneclean (Bio 101, La Jolla, CA). Double-stranded PCR fragments were sequenced by using Sequenase (United States Biochemical) as described in Winship, P.R. (1984), Nucleic Acids Rev., 17:1266. Double-stranded plasmids purified through CsCl gradients were sequenced with a Sequenase kit (United States Biochemical).

Computer Analysis of Sequences. Nucleotide sequences of HEV strains were compared using the Genetics Computer Group (Madison, WI) software package (Devereaux, J. et al. (1984), Nucleic Acids Rev., 12:387-395, version 7.5, on a VAX 8650 computer (at the National Cancer Institute, Frederick, MD)).

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EXAMPLE 2

Construction of a Recombinant Expression Vector, P63-2.

A plasmid containing the complete ORF-2 of the genome of HEV strain SAR-55, Tsarev, S.A. et al. (1992), Proc. Natl. Acad. Sci. USA, 89:559-563), was used to obtain a restriction fragment NruI-BglII. NruI cut the HEV cDNA five nucleotides upstream of the ATG initiation codon of ORF-2. An artificial Bgl II site previously had been placed at the 3' end of HEV genome just before the poly A sequence (Tsarev, S.A. et al. (1992), Proc. Natl. Acad. Sci. USA, 89:559-563). To insert this fragment into pBlueBac-Transfer vector (Invitrogen) a synthetic polylinker was introduced into the unique NheI site in the vector. This polylinker contained Bln I and Bgl II sites which are absent in both HEV cDNA and pBlueBac sequences. The NruI-BglII ORF-2 fragment was inserted in Bln I-BglII pBlueBac using an adapter as shown in Fig. 1.

EXAMPLE 3

Expression of P63-2 in SF9 Insect Cells.

p63-2 and AcMNPV baculovirus DNA (Invitrogen) were cotransfected into SF9 cells (Invitrogen) by the Ca precipitation method according to the Invitrogen protocol - By following this protocol; the AcMNPV baculovirus DNA can produce a live intact baculovirus which can package p63-2 to form a recombinant baculovirus. This recombinant baculovirus was plaque-purified 4 times. The resulting recombinant baculovirus 63-2-IV-2 was used to infect SF9 cells.

SDS-PAGE and Western blot. Insect cells were resuspended in loading buffer (50 mM Tris-HCl, pH 6.8, 100 mM DTT, 2% SDS, 0.1% bromphenol blue and 10% glycerol) and SDS-polyacrylamide gel electrophoresis was performed as described, Laemmli, U.K. (1970), Nature, 227:680. Gels were stained with coomassie blue or proteins were electroblotted onto BA-85 nitrocellulose filters (Schleicher & Schuell). After transfer, nitrocellulose membranes were blocked in PBS

containing 10% fetal calf serum and 0.5% gelatin. As a primary antibody, hyperimmune serum of chimpanzee-1313 diluted 1:1000 was used. As a secondary antibody, phosphatase-labeled affinity-purified goat antibody to human IgG (Kirkegaard & Perry Laboratories, Inc.) diluted 1:2000 was used. Filters were developed in Western blue stabilized substrate for alkaline phosphatase (Promega). All incubations were performed in blocking solution, and washes were with PBS with 0.05% Tween-20 (Sigma).

Expression of HEV ORF-2. The major protein synthesized in SF9 cells infected with recombinant baculovirus 63-2-IV-2 was a protein with an apparent molecular weight of 74 KD (Fig. 2A, lane 3). This size is a little larger than that predicted for the entire ORF-2 (71 KD). The size difference could be due to glycosylation of the protein since there is at least one potential site of glycosylation (Asn-Leu-Ser) in the N-terminal part. This protein was not detected in noninfected cells (Figure 2A, lane 1) or in cells infected with wild-type nonrecombinant baculovirus (Figure 2A, lane 2). In the latter case, the major protein detected was a polyhedron protein. When the same lysates were analyzed by Western blot (Figure 2B) with serum of chimp-1313 (hyperimmunized with HEV), only proteins in the recombinant cell lysate reacted (lane 3) and the major band was again represented by a 74 KD protein (Fig. 2B). Minor bands of about,25, 29, 35, 40-45 and 55-70 kDa present in the Coomassie-stained gel (Fig. 2A, lane 3) also reacted with serum in the Western blot (Figure 2B, lane 3). Some of the bands having molecular weights higher than 74 KD result from different extents of glycosylation while the lower molecular weight bands could reflect processing and/or degradation. Serum drawn from Chimp-1313 prior to inoculation with HEV did not react with any of the proteins by Western blot.

EXAMPLE 4

Immunoelectron Microscopy of Recombinant Infected SF9 Cells.

$5x10^6$ recombinant infected SF9 cells were sonicated in CsCl (1.30 g/ml) containing 10 mM Tris-HCl, pH 7.4, 0.3% sarcosyl and centrifuged 68 h, at 40,000 rpm (SW60Ti). 50 ul of the fraction, which had the highest ELISA response and a buoyant density of 1.30 g/ml was diluted in 1 ml PBS and 5 ul of chimp-1313 hyperimmune serum was added. The hyperimmune serum was prepared by rechallenging a previously infected chimp with a second strain of hepatitis E (Mexican HEV). Samples were incubated 1 h at room temperature and then overnight at 4°C. Immune complexes were precipitated using a SW60Ti rotor at 30,000 rpm, 4°C, 2 h. Pellets were resuspended in distilled water, negatively stained with 3% PTA, placed on carbon grids and examined at a magnification of 40,000 in an electron microscope EM-10, Carl Zeiss, Oberkochen, Germany.

Detection of VLPs. Cell lysates from insect cells infected with wild-type or recombinant baculovirus 63-2-IV-2 were fractionated by CsCl density centrifugation. When fractions of the CsCl gradient from the recombinant infected insect cells were incubated with Chimp-1313 hyperimmune serum, two kinds of virus-like particles (VLP) covered with antibody were observed in the fraction with buoyant density of 1.30 g/ml: first (Fig. 3A-1 to Fig. 3A-4), antibody covered individual particles that had a size (30 nm) and morphological structure suggestive of HEV, second (Fig. 3B), antibody-coated aggregates of particles smaller than HEV (about 20 nm) but which otherwise resembled HEV. Direct EM showed the presence of a very heterogenous population of objects including some of 30 and 20 nm in diameter respectively, which looked like virus particles but, in the absence of bound antibody, could not be confirmed as HEV. A number of IEM experiments suggested that at least some of the protein(s) synthesized from the ORF-2 region of the HEV

genome, had assembled into a particulate structure. It was observed that insect cells at a later stage of infection, when the proportion of smaller proteins was higher, consistently gave better results in ELISA. Therefore, unfractionated lysates of recombinant insect cells from a later stage of infection were used as antigen in ELISA in subsequent tests.

EXAMPLE 5

Detection by ELISA Based on Antigen from Insect Cells Expressing Complete ORF-2 of Anti-HEV Following Infection with Different Strains of HEV.

$5x10^6$ SF9 cells infected with 63-2-IV-2 virus were resuspended in 1 ml of 10 mM Tris-HCl, pH 7.5, 0.15M NaCl then were frozen and thawed 3 times. 10 ul of this suspension was dissolved in 10 ml of carbonate buffer (pH 9.6) and used to cover one flexible microliter assay plate (Falcon). Serum samples were diluted 1:20, 1:400 and 1:8000, or 1:100, 1:1000 and 1:10000. The same blocking and washing solutions as described for the Western blot were used in ELISA. As a secondary antibody, peroxidase-conjugated goat IgG fraction to human IgG or horse radish peroxidase-labelled goat anti-Old or anti-New World monkey immunoglobulin was used. The results were determined by measuring the optical density (O.D.) at 405 nm.

To determine if insect cell-derived antigen representing a Pakistani strain of HEV could detect anti-HEV antibody in cynomolgus monkeys infected with the Mexican strain of HEV, 3 monkeys were examined (Figs 4A-4C). Two monkeys cyno-80A82 (Fig. 4A) and cyno-9A97 (Fig. 4B) were infected with feces containing the Mexico '86 HEV strain (Ticehurst, J. et al. (1992), J. Infect. Dis., 165:835-845) and the third monkey cyno-83 (Fig. 4C) was infected with a second passage of the same strain. As a control, serum samples from cyno-374 (Fig. 4D), infected with the Pakistani HEV strain SAR-55, were tested in the same experiment. All 3 monkeys infected with the Mexican strain seroconverted to anti-HEV. Animals from the first

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passage seroconverted by week 15 and from the second passage by week 5. Interestingly, the highest anti-HEV titer among the 4 animals, was found in cyno-83 (Fig 4C) inoculated with the second passage of the Mexican strain. Cynos inoculated with the first passage of the Mexican strain developed the lowest titers while those inoculated with the first passage of the Pakistani strain developed intermediate titers.

EXAMPLE 6

Specificity of Anti-HEV ELISA Based on Antigen from Insect Cells Expressing Complete ORF-2.

To estimate if the ELISA described here specifically detected anti-HEV to the exclusion of any other type of hepatitis related antibody, serum samples of chimps were analyzed, in sets of four, infected with the other known hepatitis viruses (Garci, P. et al. (1992), J. Infect. Dis., 165:1006-1011; Farci, P. et al. (1992), Science (in press); Ponzetto, A. et al. (1987) J Infect. Dis., 155: 72-77; Rizzetto; m.et al. (1981) Hepatology 1: 567-574; reference for chimps - 1413, 1373, 1442, 1551 (HAV); and for chimps - 982, 1442, 1420, 1410 (HBV); is unpublished data from Purcell et al) (Table 1). Samples of pre-inoculation and 5 week and 15 week post-inoculation sera were analyzed in HEV ELISA at serum dilutions of 1:100, 1:1000 and 1:10000. None of the sera from animals infected with HAV, HBV, HCV and HDV reacted in the ELISA for HEV antibody, but all 4 chimps inoculated with HEV developed the IgM and IgG classes of anti-HEV.

Table 1. Serological assay of anti-HEV antibody in chimpanzees infected with different hepatitis viruses (Hepatitis A, B, C, D, E)

chimp	inoculated virus	week of seroconversion for inoculated virus	preserum		weeks post-inoculation					
					5		15		20/25	
			IgG	IgM	IgG	IgM	IgG	IgM	IgG	IgM
Chimp-1413	HAV	5	-	-	-	-	-	-		
Chimp-1373	HAV	7	-	-	-	-	-	-		
Chimp-1442	HAV	5	-	-	-	-	-	-		
Chimp-1451	HAV	5	-	-	-	-	-	-		
Chimp-982	HBV	3	-	-	-	-	-	-		
Chimp-1442	HBV	7	-	-	-	-	-	-	-	-
Chimp-1420	HBV	9	-	-	-	-	-	-		
Chimp-1410	HBV	5	-	-	-	-	-	-		
Chimp-51	HCV	10	-	-	-	-	-	-		
Chimp-502	HCV	12	-	-	-	-	-	-		
Chimp-105	HCV	28	-	-	-	-	-	-		
Chimp-793	HCV	13	-	-	-	-	-	-		
Chimp-904	HDV	8	-	-	-	-	-	-		
Chimp-814	HDV	7	-	-	-	-	-	-		
Chimp-800	HDV	10	-	-	-	-	-	-		
Chimp-29	HDV	10	-	-	-	-	-	-	-	-
Chimp-1310	HEV	5	-	-	1:10,000	1:100	1:10,000	-		
Chimp-1374	HEV	3	-	-	1:8000	-*	1:8000	-		
Chimp-1375	HEV	3	-	-	1:8000	1:400	1:400	-		

Table 1 (cont'd.)

Chimp-1313	HEV1st°**	5	-	-	1:10,000	1:100	1:1000	-
Chimp-1313	HEV2nd°**	0.5	1:100	-	1:10,000	-	1:10,000	-

* Chimp-1374 was positive for IgM anti-HEV three and four weeks post-inoculation (see Fig.5)

** Chimp-1313 was inoculated with HEV twice. 1st inoculation with pooled samples of 7 Pakistani patients. 2nd inoculation 45 months later with Mexican strain of HEV.

EXAMPLE 7

Determination of the Host Range of the SAR-55 Strain of HEV in Non-Human Primates.

Different primate species were inoculated intravenously with a standard stool suspension of HEV and serial serum samples were collected to monitor for infection. Serum ALT levels were determined as an indicator of hepatitis while seroconversion was defined as a rise in anti-HEV. The results were compared with those obtained in cynomolgus monkeys and chimpanzees.

Both rhesus monkeys inoculated with HEV (Table 2) demonstrated very prominent peaks of alanine aminotransferase activity as well as a strong anti-HEV response. The peak of alanine aminotransferase activity was observed on day 35 for both animals, and seroconversion occurred on day 21. The maximum titer of anti-HEV was reached on day 29. Both African green monkeys used in this study (Table 2) developed increased alanine aminotransferase activity and anti-HEV. Although African green money 230 died 7 weeks after inoculation, proof of infection was obtained before that time. Peak alanine aminotransferase activity for monkey 74 exceeded the mean value of preinoculation sera by about three times and for monkey 230 by about five times. Peaks of alanine aminotransferase activity and seroconversion appeared simultaneously on days 28 and 21 in monkeys 74 and 230, respectively.

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Table 2. Biochemical and serologic profiles of HEV infection in eight primate species.

Animal	Alanine aminotransferase (units/L)			Anti-HEV IgG	
	Preinoculation, mean (SD)	Day	Value	Day first detected (titer)	Maximum titer
Chimpanzee					
1374	51(12)	27	114	27(1:400)	1:8000
1375	41(14)	27	89	27(1:400)	1:8000
Cynomolgus monkey					
374*	46(20)	26	608	19(1:400)	1:8000
381*	94(19)	35	180	28(1:20)	1:8000
Rhesus monkey					
726	43(6)	35	428	21(1:20)	1:8000
938	29(10)	35	189	21(1:20)	1:8000
African green monkey					
74	72(21)	28	141	28(1:400)	1:8000
230	102(45)	21	334	21(1:8000)	1:8000
Pigtail macaque					
98	37(8)	21	47	21(1:400)	1:8000
99	41(6)	28	59	21(1:400)	1:8000
Tamarin					
616	28(7)	70	41	-	
636	19(4)	7, 56	30	-	
Squirrel monkey					
868	90(35)	40	355	41(1:20)	1:20
869	127(63)	42	679	35(1:20)	1:20
Owl monkey					
924	41(7)	35	97	21(1:20)	1:8000
925	59(6)	49, 91†	78,199†	21(1:20)	1:8000

NOTE. -, no anti-HEV detected.
* Previously studied using fragments of HEV proteins expressed in bacteria as antigen [18].
† Biomodal elevation of alanine aminotransferase.
SD = standard deviation.

Pigtail macaque 99 demonstrated an increase in alanine aminotransferase activity > 3 SD above the mean value of preinoculation sera, while pigtail macaque 98 did not. However, both monkeys seroconverted on day 21 and the anti-HEV titers were equivalent to those of the chimpanzees and Old World monkeys. Because of the low peak alanine aminotransferase values in the pigtail macaques, the possibility of immunization instead of infection with HEV cannot be completely ruled out. However, immunization is unlikely for several reasons. First, immunization in either of 2 tamarins, which are only one-fourth as large as the pigtail macaques but received the same amount of inoculum was not observed. Second, it is well known that the amount of HEV excreted in feces is usually very small, and 0.5 mL of the 10% suspension of feces used in this study is unlikely to contain an amount of antigen sufficient to immunize an animal, especially when inoculated intravenously.

Neither tamarin inoculated in this study had a significant rise in alanine aminotransferase activity or development of anti-HEV (Table 2). Therefore, these animals did not appear to be infected. The squirrel monkeys did develop anti-HEV, but at significantly lower levels than chimpanzees or Old World monkeys (Table 2). In addition, seroconversion occurred later in other animals. Squirrel monkey 868 seroconverted on day 41 and 869 on day 35. The anti-HEV titer was not > 1:20 at any time during > 3 months of monitoring and clearly was waning in both animals after reaching a peak value on days 47-54. However, the increases in alanine aminotransferase activity were rather prominent in both animals and were temporally related to the time of seroconversion.

The owl monkeys responded to HEV infection about as well as the Old World monkey species (Table 2). Both owl monkeys seroconverted on day 21 and by day 28 the anti-HEV titer had reached a value of 1:8000. Alanine amino-

transferase activity peaked on day 35 in owl monkey 924 but not until day 49 in monkey 925.

EXAMPLE 8

Detection of IgM and IgG Anti-HEV in Chimps.

In both chimps, the serum ALT levels increased about 4 weeks post-inoculation (Table 2, Fig. 5). Both chimps seroconverted at the time of ALT enzyme elevation or earlier (Fig. 5A, 5C). Levels of IgM anti-HEV also were determined for the chimps. In chimp-1374, the titer of IgM anti-HEV (Fig 5B) was not as high as the IgG titer (Fig 5A) and waned over two weeks. Although both IgG and IgM antibodies were first detected for this animal on day 20, the titer of IgM anti-HEV was the highest while the titer of IgG was the lowest on that day, but then rose and stayed approximately at the same level for more than three months. In chimp-1375, only IgM anti-HEV was detected on day 20 (Fig. 5D). The titer was higher than in chimp-1374 and IgM anti-HEV was detected during the entire period of monitoring. IgG anti-HEV was first observed in this animal on day 27 (Fig. 5C) and remained at approximately the same level throughout the experiment.

EXAMPLE 9

Comparison of ELISA Based on Complete ORF-2 Protein Expressed in Insect Cells With That Based on Fragments of Structural Proteins Expressed in E. coli.

To estimate if expression of the complete ORF-2 region of the HEV genome in eukaryotic cells had any advantage over expression of fragments of structural proteins in *E. coli*, we used the former antigen in ELISA to retest cynomolgus monkey sera that had been analyzed earlier (Tsarev, S.A. et al. (1992), Proc. Natl. Acad. Sci USA, 89:559-563; and Tsarev, S.A. et al. (1993) J. Infect. Dis. (167:1302-1306)), using the antigen fragments expressed in bacteria (Table 3).

Table 3. Comparison of ELISA based on antigen from insect cells expressing complete ORF-2 with that based on antigen from E.coli expressing fragments of structural proteins

Cyno #	antigen derived from bacterial cells (Portion of ORF-2)*	antigen derived from insect cells (Complete ORF-2)		
		anti-HEV		
	day anti-HEV first detected	first detected day	titer	max. titer
Cyno-376	28	21	1:400	1:8000
Cyno-369	54	40	1:100	1:8000
Cyno-374	19	19	1:400	1:8000
Cyno-375	26	26	1:400	1:8000
Cyno-379	21	19	1:100	1:8000
Cyno-381	28	28	1:400	1:8000

*The sera were also tested with less sensitive ORF-3 antigen.

Tsarev, S.A. et al. (1993), J. Infect. Dis. 168:369-378

For 3 of the 6 monkeys examined by ELISA, the antigen expressed in insect cells detected seroconversion earlier than the antigen expressed in *E. coli*. Using the insect cell-derived antigen, we were able to detect anti-HEV antibody in sera from all six monkeys at the highest dilution tested (1:8000). With *E. coli*-cell derived antigen (Burma Strain) no information about anti-HEV titers were obtained, since all sera were tested only at a dilution of 1:100 (Tsarev, SA et al (1992) Proc. Nat. Acad. Sci. USA; 89:559-563; Tsarev et al. (1993) J. Infect. Dis. (167:1302-1306)).

In another study, hepatitis E virus, strain SAR-55 was serially diluted in 10-fold increments and the 10^{-1} through 10^{-5} dilutions were inoculated into pairs of cynomolgus monkeys to titer the virus. The serum ALT levels were measured to determine hepatitis and serum antibody to HEV was determined by the ELISA method of the present invention (data in figures) or by Genelab's ELISA (three ELISAs, each based on one of the antigens designated 4-2, 3-

2 and 612 in Yarbrough et al. (J. Virol., (1991) 65:5790-5797) (data shown as positive (+) or negative (-) test at bottom of Figures 6 a-g). All samples were tested under code.

The ELISA method of the present invention detected seroconversion to IgG anti-HEV in all cynos inoculated and all dilutions of virus.

In contrast, Genelab's results were strikingly variable, as summarized below.

Table 4.

Dilution of Virus	Genelab's ELISA	ELISA of Present Invention
10^{-1}	did not test	positive
10^{-2}	positive for both animals, limited duration	positive
10^{-3}	negative for both animals	positive
10^{-4}	Cyno 389: positive for IgM and IgG	positive
	Cyno 383: negative	positive
10^{-5}	Cyno 386: negative	positive
	Cyno 385: positive	positive

Since Cyno 385 (10^{-5}) was positive in ELISA tests both by Genelabs and the present invention, the 10^{-4} (ten times more virus inoculated) and 10^{-3} (100 times more virus inoculated) would also have been expected to be positive. The present invention scored them as positive in contrast to Genelab's ELISA test which missed both positives at 10^{-3} and one at 10^{-4} even though the ALT levels of Cyno 383 and 393 suggested active hepatitis. Therefore, the data support the advantages of the present ELISA method over the prior art methods of detecting antibodies to HEV.

EXAMPLE 10

Comparison Of ELISAs Based On Recombinant ORF-2 Antigens Consisting Of Either A 55 kDa Protein Expressed From The Complete ORF-2 Region Of The Pakistani SAR-55 Strain Of HEV Or Of Shorter Regions Of ORF-2 Expressed As Fusion Proteins In Bacteria.

As described in Example 3 and as shown in Figures 2A and 2B, a number of proteins of varying molecular weights are expressed in insect cells infected with the recombinant baculovirus containing the complete ORF-2. A protein with a molecular weight of approximately 55 kDa was partially purified from $5x10^8$ SF-9 cells harvested seven days post-inoculation as follows: The infected cells were centrifuged, resuspended in 10 ml of 10 mM Tris-HCl (pH 8.0), 50 mM NaCl, containing 40 μg/ml of phenylmethylsulfonyl fluoride (Sigma, St. Louis, Missouri), sonicated to disrupt the cells and the lysate was centrifuged at 90,000xg at 4°C for 30 min. The supernatant was loaded onto a DEAE-sepharose CL-6B (Pharmacia, Uppsala, Sweden) column equilibrated with 10 mM Tris-HCl (pH 8..0), 50 mM NaCl. The column was washed with loading buffer and the 55 kDa protein was eluted in 10 mM Tris-HCl (pH 8.0) 250 mM NaCl. Fractions containing the 55 kDa protein were combined and the protein was precipitated by addition of 3 g of $(NH_4)_2SO_4$ to 10 ml of the protein solution. The protein pellet was dissolved in 10 mM Tris-HCl (pH 8.0), 50 mM NaCl. The 55 kDa protein was then used as the insect cell-expressed HEV antigen in ELISA in comparison testing against ELISAs based on either one of two HEV antigens expressed in bacteria, (3-2 (Mexico) (Goldsmith et al., (1992) Lancet, 339:328-331) or SG3 (Burma) (Yarbough et al., (1993) Assay development of diagnostics tests for hepatitis E. In "International Symposium on Viral Hepatitis and Liver Disease. Scientific program and abstract volume." Tokyo:VHFL, p 87, Abstract # 687). These bacterial antigens were fusion proteins of the 26 kDa glutathione-S-transferase (GST) and either the antigenic sequence 3-2 (M) consisting

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of 42 amino acids located 6 amino acids upstream of the C-terminus of ORF-2 (Yarbough et al., (1991) J. Virol., 65:5790-5797) or the 327 C-terminal amino acids of ORF-2 (Yarbough et al., (1993)). The ELISAs were carried out as follows.

Sixty ng per well of the 55 kDa protein or 200 ng per well of the fusion antigens in carbonate buffer (pH 9.6) were incubated in wells of a polystyrene microtiter assay plate (Dynateck, S. Windham, ME) for 2 h at 37°C. Plates were blocked with PBS containing 10% fetal calf serum and 0.5% gelatin. Serum samples from cynomolgus monkeys inoculated intravenously (note: cynos 387 and 392 were inoculated orally) with a dilution of feces containing the SAR-55 strain of HEV ranging from 10^{-1} through 10^{-8} as indicated in Table 5 and Figures 7A-7J and 8A-8D were diluted 1:100 in blocking solution. Peroxidase-conjugated goat anti-human IgM (Zymed, San Francisco, CA) diluted 1:1000 or 1:2000, or peroxidase-labelled goat anti-human immunoglobulin diluted 1:1000 was used as the detector antibody.

In all of the ELISA tests except those for the two orally inoculated monkeys, cyno-387 and cyno-392, the 55 kDa and the fusion antigens were tested concurrently in the same laboratory so that the only variable was the antigen used. Criteria for scoring positive reactions in anti-HEV ELISA with the 55 kDa antigen were an optical density value ≥ 0.2 and greater than twice that of a pre-inoculation serum sample for the same animal. In addition, since both antigens expressed in bacteria were fusion proteins with GST, the optical density of a sample tested with these antigens had to be 3 times higher than that obtained with non-fused GST in order to be considered positive (Goldsmith et al., (1992)).

RESULTS

Both cynomolgus monkeys (377, 378) inoculated with the 10^{-1} dilution of the standard HEV fecal suspension had a

° pronounced increase in ALT activity at 4-5 weeks post-inoculation, indicative of hepatitis (Table 5, Figures 7A and 7B).

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Table 5. Summary of biochemical and serological events occurring in cynomolgus monkeys after inoculation with 10^{-1} to 10^{-8} dilutions of the standard stock of the SAR-55 HEV inoculum.

Cyno	Dilution of viral stock inoculum	ALT pre-inoculation mean (SD)[1]	ALT peak week	ALT peak value (U/L)	weeks post-inoculation anti-HEV was detected with 55 kDa antigen IgG	weeks post-inoculation anti-HEV was detected with 55 kDa antigen IgM	weeks post-inoculation anti-HEV was detected with fusion antigen IgG SG3	weeks post-inoculation anti-HEV was detected with fusion antigen IgG 3-2(M)	weeks post-inoculation anti-HEV was detected with fusion antigen IgM SG3	weeks post-inoculation anti-HEV was detected with fusion antigen IgM 3-2(M)
377	10^{-1}	76 (39)	5	264	4-15[†]	3-7	4-10	4-5	3-4	3-5
378	10^{-1}	50 (9)	4	285	4-15	-	-	-	-	-
394	10^{-2}	62 (14)	4	89	3-15	3-10	-	4-6	-	-
395	10^{-2}	121 (21)	15	314	5-15	-	-	-	-	-
380	10^{-3}	89 (20)	1	135	5-15*	-	6-15	-	-	-
383	10^{-3}	29 (8)	4	77	5-15	5-13	-	-	-	-
389	10^{-4}	60 (7)	15	114	6-15	6-8	-	-	-	-
393	10^{-4}	41 (4)	5	87	6-15	-	-	-	-	-
385	10^{-5}	59 (32)	7	56	11-15	-	-	7-15	-	-
386	10^{-5}	31 (4)	4	34	8-15	8-13	-	-	-	-
397	10^{-6}	60 (4)	8	94	-	-	-	-	-	-
398	10^{-6}	36 (3)	2	55	-	-	-	-	-	-
399	10^{-7}	102 (16)	2	93	-	-	-	-	-	-
400	10^{-7}	57 (4)	9	188	-	-	-	-	-	-
403	10^{-8}	33 (3)	2-3	49	-	-	-	-	-	-
406	10^{-8}	56 (4)	2	73	-	-	-	-	-	-
387	10^{-1} (oral)[§]	32 (4)	4	38	-	-	ND	-	ND	-
392	10^{-1} (oral)[§]	49 (6)	3	70	-	-	ND	-	ND	-

[1] ALT mean and standard deviation (SD) values of pre-inoculation sera.

[†] The experiment was terminated after 15 weeks.

Table 5 (cont'd.)

* The OD values of pre-inoculation sera of Cyno-380, when tested by ELISA with 55 kDa antigen, were twice as high as the mean value of pre-inoculation sera for other cynomolgus monkeys.

§ All ELISA tests except for Cyno-387 and Cyno-392 were performed in the same experiments.

- not detected. ND - not done.

All 3 antigens tested detected IgM anti-HEV in samples taken from cyno-377 3 weeks post-inoculation (Table 5, Figure 8A), but IgM anti-HEV was not detected in any samples from the second animal, cyno-378. IgG anti-HEV was detected in both animals with the 55 kDa-based ELISA, but only in cyno-377 with the ELISA based on fusion antigens. Values of OD for IgG anti-HEV were significantly higher than those for IgM anti-HEV. ELISA values obtained with the 55 kDa antigen were also significantly higher than those obtained with either of the two fusion antigens (Figures 7A and 7B). The patterns of the OD values observed in ELISA with antigens from the two sources also differed significantly. In the case of ELISA based on the fusion antigens, positive signals reached a maximum shortly after seroconversion and then waned during the 15 weeks of the experiment. In ELISA based on the 55 kDa antigen, the positive signal reached a maximum shortly after seroconversion and remained at approximately the same high level throughout the experiment (15 weeks).

Elevation in ALT activities in both monkeys (394 and 395) inoculated with a 10^{-2} dilution of the standard HEV stool suspension was significantly less pronounced at the expected time of hepatitis than in animals inoculated with the ten-fold higher dose (Table 5, Figures 7C and 7D). Cyno-395 actually had higher ALT activities prior to inoculation as well as at 15 weeks post-inoculation. The latter was probably not related to HEV infection. Weakly positive IgM anti-HEV was detected only in cyno-394 (Figure 8B) and only with ELISA based on the 55 kDa antigen. Both animals were infected, however, since IgG anti-HEV seroconversion was detected in both animals. In cyno-394, anti-HEV IgG was first detected by the 55 kDa antigen at week 3 and one week later with the 3-2(M) antigen. The SG3 (B) antigen did not detect seroconversion in cyno-395 and anti-HEV IgG was detected only with the 55 kDa antigen.

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Anti-HEV tended to diminish in titer with time in this animal.

Cyno-380 and cyno-383 were inoculated with a 10^{-3} dilution of the standard HEV fecal suspension (Table 5, Figures 7E 7F, 8C). Cyno-380 had fluctuating ALT activities before and after inoculation; therefore, ALT levels could not be used to document hepatitis E in this animal. In Cyno-383, a slight rise of ALT activities was observed (Figure 7F), which was coincident with seroconversion and, therefore, might be due to mild hepatitis E. IgM Anti-HEV was not detected in sera from cyno-380 with any of the three antigens. Cyno-380 seroconverted for IgG anti-HEV when tested by ELISA with SG3 (B) but not with 3-2(M) antigen. This animal had preexisting IgG anti-HEV when tested with the 55 kDa antigen, but there was a large increase in IgG anti-HEV starting at week 5 (Figure 7E). Identification of preexisting antibody was reported earlier in sera from another cynomolgus monkey [Ticehurst et al., (1992) J. Infect Dis., 165:835-845; Tsarev et al., (1993) J. Infect. Dis., 168:369-378]. Seroconversion occurred at the expected time but the levels of IgG anti-HEV in samples from cyno-383 remained low and detectable only with the 55 kDa antigen.

Cyno-389 and cyno-393 were inoculated with a 10^{-4} dilution of the standard HEV fecal suspension (Figures 7G, 7H, 8D, Table 5). Neither animal had a significant rise in ALT activities, although the timing of a small but distinct ALT peak in sera of cyno-393 at week 5 (Figure 7H) suggested borderline hepatitis. ELISA based on the SG3 (B) or 3-2(M) antigens scored both animals as negative for HEV infection. In contrast, the 55 kDa antigen detected IgM anti-HEV in sera of cyno-389 at weeks 6-8 post-inoculation (Figure 8D) and IgG anti-HEV from week 6 through week 15 in both animals.

Neither animal inoculated with the 10^{-5} dilution of the standard fecal suspension developed a noticeable rise in ALT activities (Figure 7I, 7J, Table 5), but, in cyno-

386, IgM and IgG anti-HEV were detected at weeks 8-13 and 8-15 respectively with the 55 kDa antigen (Figure 7J, 8E). Cyno-385 anti-HEV IgG was detected with the 55 kDa and the 3-2(M) antigen but not with SG3 (B) antigen. In contrast to previous patterns, IgG anti-HEV was detected with a fusion antigen four weeks earlier and at higher levels than with the 55 kDa antigen.

None of the animals inoculated with dilutions of the standard HEV fecal suspension in the range of 10^{-6}-10^{-8} developed antibody to any of the three HEV antigens. Increased ALT activities were not observed in those animals, except for one rather prominent peak of ALT activity at week 9 in cyno-400 (Table 5). However, the absence of seroconversion in this animal indicated that this peak probably was not related to HEV infection.

With respect to the two cynomolgus monkeys (387 and 392) inoculated orally with the 10^{-1} dilution of the 10% fecal suspension, neither monkey was infected since ALT levels did not rise and ELISA performed with the 3-2(M) and 55 kDa antigens did not detect seroconversion to HEV (Table 5).

Finally, serological evidence for HEV infection was found in all animals inoculated with decimal dilutions of the fecal suspension through 10^{-5}; none of the animals receiving higher dilutions had such evidence. Prominent hepatitis, as defined by elevated ALT, was observed only in the two monkeys infected with the 10^{-1} dilution. Significantly lower elevations of ALT activities were observed in some animals inoculated with higher dilutions of the fecal suspension while, in others, elevations were not found. Considered alone, these low ALT rises were not diagnostic of hepatitis. However, the coincidence of seroconversion and appearance of these ALT peaks suggests the presence of mild hepatitis in these animals. Anti-HEV IgG seroconversion was detected in all animals inoculated with dilutions of fecal suspension ranging from 10^{-1} -10^{-5}.

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° A tendency toward lower levels of IgG anti-HEV and delayed seroconversion was observed in animals inoculated with higher dilutions of the stock.

In sum, the 55 kDa Pakistani ORF-2 antigen was more efficient than either the 3-2(M) or SG3 (B) antigen for detecting IgM and IgG anti-HEV in cynomolgus monkeys infected with the Pakistani strain of HEV. For example, for all animal sera except those from cyno-385, detection of IgG or IgM anti-HEV by ELISA was more efficient with the 55 kDa antigen than with either the 3-2(M) or SG3 antigen. ELISA with the 55 kDa antigen produced internally consistent and reproducible results, detecting IgG anti-HEV in all ten animals inoculated with a fecal dilution of 10^{-5} or lower. The magnitude of ELISA signals also decreased as the inoculum was diluted. The fusion antigens did not produce consistent results between the pairs of animals. Only one of each pair of animals inoculated with the 10^{-1}, 10^{-2}, 10^{-3}, or 10^{-5} dilution showed seroconversion to IgG anti-HEV, and only a single seroconversion for IgM anti-HEV was detected with these antigens. Neither of the animals inoculated with the 10^{-4} dilution of the original inoculum seroconverted to either of the two fusion antigens even though sera from one animal (cyno-393) had sustained high levels of anti-HEV IgG when assayed with the 55 kDa antigen. Although, as discussed above, ELISA for IgM anti-HEV was significantly less sensitive than ELISA for cynomolgus IgG anti-HEV, the 55 kDa antigen was able to detect anti-HEV IgM in more animals than the 3-2(M) or SG3 (B) antigen. In sum, a definitive conclusion about the infectious titer of the Pakistani viral inoculum used in this study could not be made with the combined data from the 3-2(M) and SG3 (B) based ELISA but could be made with data obtained with the 55 kDa Pakistani ELISA alone.

With respect to cyno-385, the difference in anti-HEV IgG detection between the two test results was four weeks. These data suggest the presence of a distinct

epitope in the 3-2(M) antigen recognized by this animal that is absent in the larger 55 kDa and SG3 (B) antigens. When total insect cell lysate, which contained both complete ORF-2 (75 kDa) and 55 kDa proteins, was used as antigen to retest these samples, the results were the same as when 55 kDa was used alone. This finding suggests that the 55 kDa protein may not lack 3-2 epitope amino acids but rather that the conformation of the 3-2 epitope sequence differed among all three antigens used in this study. Finally, it is interesting to note that despite the fact that antigen SG3 (B) contained a longer portion of ORF-2 and included the entire sequence of epitope 3-2, it did not detect more positive sera than the 3-2(M) antigen.

EXAMPLE 11

Determination of the Infectious Titer of the HEV SAR-55 Viral Stock BY RT-PCR

Knowledge of the infectious titer of inocula is critical for interpretation of much of the data obtained in experimental infections of animal models. However, until now the infectious titer of an HEV viral stock has not been reported. Ten-fold dilutions of the fecal suspension containing the SAR-55 strain of HEV were extracted and RT-PCR amplification was performed as follows to determine the highest dilution in which HEV genomes could be detected. 200 ul of fecal suspension was mixed with 0.4 ml of 1.5M NaCl plus 15% polyethylene glycol (PEG) 8000 and kept overnite at 4°C. Pellets were collected by centrifugation for 3 minutes in a microcentrifuge (Beckman, Palo Alto, CA) at 16,000g and dissolved in 475 ul of solution containing 4.2M guanidine thiocyanate, 0.5% N-lauroylsarcosine, 0.25M TRIS-HCl (pH 8.0). 0.15 M dithiothreitol (DTT), and 1.0μg of tRNA. Fifty microliters of 1M TRIS-HCl (pH 8.0), 100 mM EDTA, and 10% SDS was then added. The RNA was extracted twice with phenol-chloroform (1:1) at 65°C, followed by chloroform extraction at room temperature. To the upper phase, 250 μL of 7.5 M ammonium acetate was added, and

nucleic acids were precipitated with 0.6mL of 2-propanol, washed with 75% ethanol, washed with 100% ethanol, and used for reverse transcription (RT) PCR.

For detection of the HEV genome, two sets of nested primers were used that represented sequences from the 3' region (ORF-2) of the SAR-55 genome. Primers for reverse transcription and the first PCR are shown as SEQ ID NO:99: GTATAACGGATCCACATCTCCCCTTACCTC and SEQ ID NO:100: TACAGATCTATACAACTTAACAGTCGG respectively. Primers for the second PCR are shown as SEQ ID NO: 101: GCGGCAGATCTCACCGACACCATTAGTAC and SEQ ID NO:102: TAACCTGGATCCTTATGCCGCCCCTCTTAG respectively. The RNA pellet was dissolved in 20 μL of 0.05 M TRIS-HCl (pH 7.6), 0.06 M KCl, 0.01 M $MgCl_2$, 0.001 M DTT, 40 units of RNasin (Promega Biotec, Madison, WI), 16 units of avian myeloblastosis virus reverse transcriptase (Promega Biotec), and 10 pmol of reverse primer and incubated 1 hour at 42°C. To 20 μL of reverse transcriptase mixture was added 100 μL of 0.01 M TRIS-HCl (pH 8.4), 0.05 M KCl, 0.0025 M $MgCl_2$, 0.0002 M each dNTP, 50 pmol of direct primer, 50 pmol of reverse primer, and 4 units of AmpliTaq (Perkin-Elmer Cetus, Norwalk, CT) under 100 μL of light mineral oil. The HEV cDNA was amplified by 35 cycles of PCR:1 min at 94°C, 1 min at 55°C, 1 min at 72°C. The products of PCR were analyzed on 1% agarose gels. Then 5 μL of this mixture was used for the second round of amplification under the same conditions, except the extension time was increased to 3 min.

The RT-PCR products produced in all dilutions of the standard HEV feces in the range from 10^{-1} to 10^{-5} (Figure 9) were separated on a 2% agarose gel and were detected by ethiduim bromide staining of the gel. A decrease in the amount of the specific PCR product at higher dilutions was observed and the highest dilution of the 10% fecal suspension in which the HEV genome was detected was 10^{-5}. Therefore, taking into account the dilution factor, the HEV genome titer was approximately $10^{6.7}$ per gram of feces.

In addition, only those dilutions that were shown by RT-PCR to contain the HEV genome were infectious for cynomolgus monkeys. Therefore, the infectivity titer of the standard fecal suspension and its genome titer as detected by RT-PCR were approximately the same. A similar correlation between RT-PCR and infectivity titer was found for one strain of hepatitis C virus [Cristiano et al., (1991) Hepatology, 14:51-55; Farci et al., (1991) N. Engl. J. Med., 25:98-104; Bukh et al., (1992); Proc. Natl. Acad. Sci U.S.A., 89:187-191)

EXAMPLE 12

Active Immunization Using The ORF-2 Protein As A Vaccine And Passive Immunization With Anti-HEV Positive Convalescent Plasma

Cynomolgus monkeys (*Macaca fascicularis*) that were HEV antibody negative (<1:10) in an ELISA based on the 55 kDa ORF-2 protein were individually housed under BL-2 biohazard containment and a suspension (in fetal bovine serum) of feces containing the Pakistani HEV strain SAR-55, diluted to contain 10,000 or 1,000 CID_{50}, was used for intravenous inoculation of animals.

For active immunization studies, baculovirus recombinant-expressed 55 kDa ORF-2 protein was purified from 5×10^8 SF-9 cells harvested 7 days post-inoculation as described in Example 10. Three mg of the purified 55 kDa protein were precipitated with alum and eight cynomolgus monkeys were immunized by intramuscular injection with 0.5 ml of vaccine containing 50 μg of the alum-precipitated 55 kDa protein. Four monkeys received a single dose and four monkeys received two doses separated by four weeks. Primates were challenged intravenously with 1,000 - 10,000 CID_{50} of HEV four weeks after the last immunization.

Four cynomolgus monkeys served as controls in the active immunization studies. Cyno-412 and 413 received one dose of placebo (0.5 ml of phosphate buffered saline) and

cyno-397 and 849 received two doses of placebo. The control animals were challenged with 1,000 - 10,000 CID_{50} of HEV.

For passive immunity studies, cyno-384 was infected with 0.5 ml of a 10% pooled stool suspension containing two Chinese HEV isolates, KS1-1987 and KS2-1987 and plasma was repeatedly collected from the animal during convalescence. (Yin et al. (1993) J. Med. Virol., 41:230-241;). Approximately 1% of the blood of cyno-396 and cyno-399 and 10% of the blood of cyno-401 and cyno-402 was replaced with convalescent plasma from cyno-384 having an HEV antibody titer of 1:10,000. Animals were challenged with 1000 CID_{50} of HEV two days after infusion of the plasma. As a control, 10% of the blood of cyno-405 was replaced with anti-HEV negative plasma obtained from cyno-384 prior to infection with HEV. Cyno-405 was then challenged with 1000 CID_{50} of HEV.

For both the passive and active immunization studies, percutaneous needle biopsies of the liver and samples of serum and feces were collected prior to inoculation and weekly for 15 weeks after inoculation. Sera were assayed for levels of alanine amino transferase (ALT) with commercially available tests (Metpath Inc., Rockville, MD) and biochemical evidence of hepatitis was defined as a two-fold or greater increase in ALT. Liver biopsies were examined under code and the anti-HEV ELISA utilized was described in Example 10. RNA extraction and RT-PCR were performed as in Example 11 except that RNA from 100 μl of serum or from 100 μl of 10% fecal suspension was extracted with TRIzol Reagent (Gibco BRL, Gaithersburg, Maryland) according to the manufacturer's protocol. For quantification, PCR positive serial sera or feces from each animal were combined and serially diluted in ten-fold increments in calf serum. One hundred μl of each dilution were used for RNA extraction and RT-PCR as described earlier in this Example. The PCR protocol used in this study could

detect as few as 10 CID_{50} of HEV per ml of serum and as few as 100 CID_{50} per gram of feces.

Peak ALT values of weekly serum samples for 5 weeks prior to inoculation and for 15 weeks post-inoculation were expressed as ratios (post/pre) for each animal. The geometric mean of the ratios from the control group of animals was compared with that from the passively or actively immunized animals using the Simes test (Simes, R.J. (1986) Biometrika, 73:751-754).

The durations of viremia and virus shedding in feces and the HEV genome titers in the control group of animals were compared with those in passively or actively immunized animals using the Wilcoxon test [Noether, G. (1967) in *Elements of nonparametric statistics* (John Wiley & Sons Inc., New York), pp. 31-36.]. The same test was used to compare the above parameters between passively and actively immunized animals.

For statistical analysis, serum samples that had <10 HEV genomes in 1 ml of serum were assigned a titer of 1:1 and fecal samples that had <100 HEV genomes in 1 g of feces were assigned a titer of 1:10.

RESULTS

Course of hepatitis E infection in nonimmunized animals.

In 3 of 5 nonimmunized animals that were challenged with HEV, biochemical evidence of hepatitis was documented by at least a two-fold increase in serum ALT values. In two animals, significant increases in ALT activity were not found. However, histopathological data documented hepatitis in all 5 animals as shown in Table 6.

Table 6. Histopathological, biochemical, serological, and virological profiles of vaccinated and control animals challenged with HEV.

Animal # and category	Anti-HEV positive plasma (%) or 55 kDA protein (μg)	Cumulative score of histopathology (number of weeks detected)*	Peak ALT value in U/L (week)		HEV antibody titer at the time of challenge	HEV genome			
			pre-inoculation	post-inoculation		serum		feces	
						week detected (duration)	mean $\log_{10}$ titer per ml	week detected (duration)	mean $\log_{10}$ titer per gram
control									
405	0	10+ (8)	67 (0)	143 (9)	<1:10	1-11 (11)	3	1-11 (11)	5.7
412	0	2+ (1)	34 (0)	45 (3)	<1:10	1-4 (4)	3	2-5 (4)	7
413	0	4+ (4)	44 (0)	261 (6)	<1:10	2-7 (6)	4.7	1-7 (7)	7
849	0	1+ (1)	79 (-2)	133 (2)	<1:10	1-4 (4)	3.7	1-4 (4)	7
397	0	3+ (3)	52 (-3)	139 (7)	<1:10	2-6 (5)	4.7	1-7 (7)	7
passive IP†									
396	1%	1+ (1)‡	33 (0)	53 (6)	1:40	3-5 (3)	4	1-6 (6)	5.7
399	1%	0 (0)	69 (0)	63 (11)	1:40	2-4 (3)	3	1-4 (4)	4

401	10%	0 (0)	55 (0)	45 (5)	1:200	3 (1)	3.6	1-3 (3)	5.7
402	10%	0 (0)	59 (0)	35 (2)	1:200	4-6 (3)	1	2-6 (5)	5.7
									20
active IP†									
003	50 μg	0 (0)	34 (-3)	50 (6)	1:10,000	0	<1	2-4 (3)	3
009	50 μg	0 (0)	34 (-2)	38 (6)	1:1,000	0	<1	0	<2
013§	50 μg	0 (0)	44 (-3)	36 (7)	1:100	0	<1	1-2 (2)	3
414	50 μg	0 (0)	65 (0)	73 (8)	1:1,000	0	<1	2 (1)	2
398	2×50 μg	0 (0)	31 (0)	41 (2)	1:10,000	0	<1	0	<2
407	2×50 μg	0 (0)	150 (0)	213 (4)	1:10,000	0	<1	0	<2

*Necro-inflammatory changes in the liver were rated as 1+, 2+, 3+, 4+ and the weekly scores were summed.
†Immunoprophylaxis
‡Necro-inflammatory changes rated 1+ were detected during two weeks in cyno-396, however, they were consistent with viral hepatitis only during one week.
§Cyno 013 died 9 weeks after challenge.

Necro-inflammatory changes ranged between 1+ and 2+ on a scale of 1+ to 4+ and were temporally associated with elevations of ALT activities in those animals with such elevations.

All control animals seroconverted to HEV 3-5 weeks post-challenge and developed maximum HEV antibody titers ranging from 1:1,000 to 1:32,000. There was a good correlation between the severity of infection, hepatitis, and the level of anti-HEV response. Cyno-405, which had the highest cumulative score for hepatitis, also had the longest period of viremia and viral excretion and the highest level of anti-HEV (Table 6). The duration of viral shedding in feces was the same as, or longer than, that of the viremia. For all of the control animals, titers of the HEV genome in serum were lower (10^{-3} - $10^{-4.7}$) than the titers in feces ($10^{-5.7}$-10^{-7}). In all five of these animals, viremia and virus shedding in feces were detected for 4-11 weeks and for an average of 4.2 weeks after seroconversion (range 2-9 weeks).

Passive immunization. Cyno-396 and 399, which had approximately 1% of their blood replaced with anti-HEV positive convalescent plasma, had an HEV antibody titer of 1:40 when it was determined two days post-transfusion (at the time of challenge) (Table 6). A two-fold fall in HEV antibody titer was observed in both animals 1 week post-transfusion and HEV antibodies fell below the detectable level (<1:10) by 2 weeks post-transfusion. Anti-HEV was again detected 5 weeks post-challenge in cyno-396 and 4 weeks post-challenge in cyno-399, indicating that infection with HEV had occurred. The maximum HEV antibody titer (1:8,000) was reached 9-10 weeks post-challenge. Neither cynomolgus monkey demonstrated a significant elevation of ALT activity after challenge. However, histologic evidence of hepatitis was detected in cyno-396 and the HEV genome was detected in serum and feces from both animals (Table 6).

Cyno-401 and 402 had approximately 10% of their blood replaced with convalescent plasma. Two days post-transfusion, at the time of challenge, the HEV antibody titer in both cynomolgus monkeys was 1:200 (Table 7).

Table 7. HEV antibody profiles in control and immunized cynomolgus monkeys.

Control animals	HEV antibody		Passively immunized animals	HEV antibody		Actively immunized animals	HEV antibody		
	titer (week first detected)	max. titer (week)		titer at the time of challenge	max. titer (week after challenge)		max. titer (week after 1st immunization)	max. titer (week after 2nd immunization)	max. titer (week after challenge)
cyno-405	1:80 (3)	1:32,000 (9)	cyno-396	1:40	1:8,000 (10)	cyno-003	1:10,000 (3)		1:10,000 (5)
cyno-412	1:100 (5)	1:10,000 (7)	cyno-399	1:40	1:8,000 (9)	cyno-009	1:10,000 (3)		1:10,000 (1)
cyno-413	1:100 (5)	1:10,000 (7)	cyno-401	1:200	1:4,000 (6)	cyno-013	1:100 (2)		1:10,000 (3)
cyno-849	1:100 (3)	1:1,000 (5)	cyno-402	1:200	1:80 (12)	cyno-414	1:1,000 (3)		1:1,000 (0)
cyno-397	1:100 (3)	1:10,000 (7)				cyno-398	1:1,000 (3)	1:10,000 (5)	1:10,000 (0)
						cyno-407	1:1,000 (4)	1:10,000 (5)	1:10,000 (0)

Anti-HEV was detected continuously in both animals during the 15 weeks after challenge and reached a maximum titer of 1:4,000 in cyno-401 but only 1:80 in cyno-402. Biochemical and histologic analyses did not reveal hepatitis in either animal. However, in both animals, HEV viremia and fecal shedding of virus were observed indicating that infection had occurred (Table 6). Thus, passive immunoprophylaxis that achieved a higher titer of antibody protected cynomolgus monkeys against hepatitis after challenge with HEV.

Active immunization. Four primates immunized with one 50 μg dose of the 55 kDa protein developed antibody to the recombinant protein ranging in titer from 1:100 to 1:10,000 (Table 7). One (cyno 013) died of an anesthesia accident 9 weeks after challenge and is included in the analyses (Table 6). The four animals that received two doses of the antigen developed HEV antibodies with titers of 1:10,000. Two of the four monkeys died following intravenous challenge with HEV. This may have also been the result of an anesthesia accident but the exact etiology could not be determined. These two monkeys were deleted from further analyses. None of the 6 remaining animals developed abnormal ALT levels or histologic evidence of hepatitis following challenge (Table 6). Cynomolgus monkeys immunized with either 1 or 2 doses of the 55 kDa protein did not develop viremia. However, 3 of 4 animals that received one dose of the immunogen excreted virus in their feces. In contrast, virus shedding was not observed in either of the two challenged animals that had received two doses of the vaccine.

Most of the actively immunized animals developed higher HEV antibody titers than did passively immunized animals. However, cyno-013 had an HEV antibody titer of 1:100 at the time of challenge, compared with a titer of 1:200 in two animals immunized passively with anti-HEV plasma. Cyno-013, however, demonstrated greater protection

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against HEV infection than the passively immunized animals. Cyno-009, which had an HEV antibody titer of 1:1,000 at the time of challenge, was completely protected against hepatitis and HEV infection (Table 6). In contrast, cyno-003 was infected and shed HEV in feces, even though it had an HEV antibody titer of 1:10,000 at the time of challenge. However, neither hepatitis nor viremia was detected in this animal or in other cynomolgus monkeys that received one dose of immunogen and had HEV antibody titers of 1:10,000 or greater.

Comparison of course of HEV infection in control and immunized animals.

As measured by histopathology, all immunized animals, with the exception of one of the passively immunized monkeys, were protected against hepatitis after intravenous challenge with HEV. Comparison of mean values for severity of hepatitis and level of viral replication between the control group and the passively and actively immunized animals indicated that, in general, the severity of infection was inversely related to the HEV antibody titer at the time of challenge and diminished in the order: unimmunized>passive immunization (1%)>passive immunization (10%)>active immunization (1 dose)>active immunization (2 doses) (Tables 6,8). However, the number of animals in each of the two subgroups of passively and actively immunized animals was not sufficient to permit statistical analysis. Therefore, statistical analysis was performed for combined passively immunized and combined actively immunized groups respectively in comparison with the combined control groups. The results of this analysis are presented in Table 8.

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Table 8. Summary of mean values of HEV infection in control and immunized animals.

Category (number) of animals	Histopathology		GM* of peak ALT U/L			HEV antibody titer at the time of challenge	HEV genome			
							Serum		Feces	
	Mean of cumulative score	Weeks	Pre-inoculation	Post-inoculation	Ratio		mean number of weeks	mean $\log_{10}$ titer	mean number of weeks	mean $\log_{10}$ titer
Control (5)	4+	3.4	53	125	2.4	<1:10	6	3.8	6.6	6.7
Passive 1% (2)†	0.5+	0.5	48	58	1.2	1:40	3	3.5	5	4.9
Passive 10% (2)†	0	0	57	40	0.7	1:200	2	2.3	4	5.7
Active 1 dose (4)†	0	0	43	47	1.1	1:3,025	0	<1	1.5	2
Active 2 doses (4)†	0	0	68	93	1.4	1:10,000	0	<1	0	<2

*Geometric mean

†Passive and active immunoprophylaxis

α - P<0.01

β - P<0.05

γ - not significant

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and they show that the histopathology scores and duration of histologic changes in the control group were statistically different from those of passively or actively immunized animals. The higher post-/pre-inoculation ratios of peak ALT values in the control group were statistically significant when compared with those of the passively or actively immunized animals, indicating protection against biochemical manifestations of hepatitis in both groups of immunized animals. The duration of viremia and the titer of HEV in the feces were significantly lower in both groups of immunized animals than in the control group. Differences in the duration of virus shedding and titer of HEV in the serum, however, were not statistically different between the control group and the passively immunized group, although these parameters were significantly different when the control group was compared with the actively immunized group. Significant differences were also found between passively and actively immunized groups of animals for duration of viremia and fecal shedding as well as for HEV titers.

In sum, the results presented in Tables 6-8 show that both passively and actively acquired HEV antibodies protected cynomolgus monkeys against hepatitis following challenge with virulent HEV. Although all 5 nonimmunized cynomolgus monkeys developed histologic evidence of hepatitis when challenged with 1,000 - 10,000 CID_{50} of SAR-55, both animals with passively acquired antibody titers of 1:200 were protected from hepatitis and one of two animals with an antibody titer as low as 1:40 also did not develop hepatitis.

However, it should be noted that actively immunized animals demonstrated complete protection against hepatitis and more effective resistance to HEV infection than did passively immunized animals. For example, in contrast to results obtained from the passively immunized animals, viremia was not detected in actively immunized

animals after challenge with HEV. An HEV antibody titer as high as 1:10,000 could be achieved in cynomolgus monkeys after one or two immunizations with the recombinant 55 kDa protein. Although one monkey (013) developed a titer of 1:100 after active immunization, this level still prevented hepatitis and viremia.

The active immunization studies also demonstrated that while a single dose of vaccine prevented HEV viremia, viral shedding in feces was still detected. However, two doses of vaccine were observed to prevent all signs of hepatitis and HEV infection. These results thus suggest that a single dose of vaccine administered, for example, to individuals before foreign travel would protect them from hepatitis E in high risk environments.

Finally, it is noted that the results presented are very similar to results reported previously for passive and active immunoprophylaxis of nonhuman primates against hepatitis A: passive immunoprophylaxis prevented hepatitis but not infection whereas vaccination prevented not only hepatitis but infection with HAV as well (Purcell, R.H. et al. (1992) Vaccine, 10:5148-5149). It is of interest that the study of immunoprophylaxis for HEV presented herein parallels the previous study of immunoprophylaxis against HAV, both in determination of the titer of antibody that protected (<1:100) and in outcome following intravenous challenge with virulent virus. Since other studies have demonstrated efficacy of comparable titers of passively and actively acquired anti-HAV in humans and have confirmed the predictive value of studies of primates in hepatitis research (Stapleton, J., et al. (1985) *Gastroenterology* 89:637-642; Innis, B.L., et al. (1992) *Vaccine*, 10: S159), it is therefore highly likely that these results in cynomolgus monkeys will be predictive of protection in humans.

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EXAMPLE 13

Direct Expression In Yeast Of Complete ORF-2 Protein And Lower Molecular Weight Fragments

Four cDNA ORF-2 fragments coding for:

1. complete ORF-2 protein (aa 1-660, MW 70979), fragment 1778-1703. (where the fragment numbers refer to the primer numbers given below)
2. ORF-2 protein starting from 34th aa (aa 34-660, MW 67206), fragment 1779-1703.
3. ORF-2 protein starting from 96th aa (aa 96-660, MW 60782), fragment 1780-1703.
4. ORF-2 protein starting from 124th aa (aa 124-660, MW 58050), fragment 1781-1703.

were obtained using PCR by using plasmid P63-2 as template and the synthetic oligonucleotides shown below: SEQ ID NO.:103 (reverse primer #1703) GCACAACCTAGGTTACTATAACTCCCGAGTTTTACC, SEQ ID NO.:104 (direct primer #1778) GGGTTCCCTAGGATGCGCCCTCGGCCTATTTTG, SEQ ID NO.:105 (direct primer #1779) CGTGGGCCTAGGAGCGGCGGTTCCGGCGGTGGT, SEQ ID NO.:106 (direct primer #1780) GCTTGGCCTAGGCAGGCCCAGCGCCCCGCCGCT and SEQ ID NO.:107 (direct primer #1781) CCGCCACCTAGGGATGTTGACTCCCGCGGCGCC.

All sequences shown in SEQ ID NOs: 103-107 contain artificial sequence CCTAGG at their 5' ends preceded by 4 nucleotides. The artificial sequence was a recognition site for Avr II (Bln I) restriction enzyme. Synthesized PCR fragments were cleaved with BlnI and cloned in the AvrII site of pPIC9 vector (Figure 10) (*Invitrogen*). Correct orientation of the fragments was confirmed by restriction analysis, using asymmetric EcoRI site present in ORF-2 sequences and in the vector. Purified recombinant plasmids pPIC9-1778 (containing fragment 1778-1703); pPIC9-1779 (containing fragment 1779-1703); pPIC9-1780 (containing fragment 1780-1703) and pPIC9-1781 (containing fragment

1781-1730) were used for transformation of yeast spheroplast (Picha strain) according to *Invitrogen* protocol. Screening of recombinant clones and analysis of expression were performed using the same protocol. These expressed proteins may be used as immunogens in vaccines and as antigens in immunoassays as described in the present application. Finally, those of skill in the art would recognize that the vector and strain of yeast used in the above example could be replaced by other vectors (e.g. pHIL-F1; Invitrogen) or strains of yeast (e.g. Saccharomyces Cerevisiae).

EXAMPLE 14

Purification and Amino Terminal Sequence Analysis of HEV ORF-2 Gene Products Synthesized in SF-9 Insect Cells Infected With Recombinant Baculovirus 63-2-IV-2

As described in Example 10, SF-9 cells were infected with recombinant baculovirus 63-2-IV-2 and harvested seven days post-inoculation. The predominant protein band present on SDS-PAGE of the insect cell lysate was approximately 55 kDa in molecular weight. Further purification of this 55 kDa band was accomplished by ion-exchange column chromatography using DEAE-sepharose with a 150-450 mM NaCl gradient. DEAE fractions were assayed for the presence of the 55 kDa band by SDS-PAGE followed by Coomassie blue staining. The peak fraction was then resolved by polyacrylamide gel electrophoresis in the absence of SDS into three bands of 55 kDa, 61 kDa and a band of intermediate molecular weight. Analysis of each protein band from the polyacrylamide gel by amino-terminal microprotein sequencing revealed that the 55 and 61 kDa proteins shared a unique N-terminus at Ala-112 of SEQ ID NO:2. It is believed that the size differences in the two ORF-2 cleavage products may reflect either different COOH-terminal cleavage of the larger product.

The third intermediate protein on the polyacrylamide gel was shown to be a baculovirus chitinase protein. The 55 and 61 kDa ORF-2 proteins were resolved

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into a single symmetrical peak fraction devoid of any chitinase by subjecting peak DEAE fractions to reverse phase HPLC using a micropore system with NaCl and acetonitrile solvents.

EXAMPLE 15

Direct Expression of 55 and 61 kDa Cleavage Products

A cDNA ORF-2 fragment coding for ORF-2 protein starting from the 112th amino acid (amino acids 112-660 of ORF-2) was obtained by PCR using plasmid p63-2 as the template. The cDNA fragment was then inserted into a pBlueBac-3Transfer vector at the BamHI-PstI site in the vector. SF9 insect cells are infected with the recombinant baculovirus generated from this vector and insect cell lysates are analyzed for the presence of the 55 and 61 kDa ORF-2 proteins by Coomassie blue staining of polyacrylamide gels. The directly expressed protein(s) may be used as immunogens in vaccines and as antigens in immunoassays as described herein.

Example 16

Kinetics of HEV ORF2 protein expression in insect cells

The expression kinetics and purification of full-length and truncated versions of the HEV ORF2 (Pakistan strain) in baculovirus-infected insect cells were examined. The 72 and 63 kD ORF2 proteins described in this Example are the same proteins as the 74 and 61 kD proteins previously described herein in Examples 3 and 14 respectively; the difference in molecular weights falling within the small range of normal variability observed for determination of molecular weights via mobility in gel electrophoresis.

Cell culture. *Spodoptera frugiperda* cells, clone 9 (Sf-9), were cultivated as monolayer cultures for plaque assays and transfections and shaker suspension cultures for virus infections to produce high-titered virus stocks and recombinant protein. Sf-9 cells were maintained at 28^{0}C and 150 rpm in Sf-900 II serum-free medium (SFM) (Life

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Technologies, Inc., Gaithersburg, MD) in dry-air incubators and were subcultured from a starting density of 0.2 x 10^6 cells/ml to a final density of 1.0 x 10^7 cells/ml as suspension cultures up to passage 70.

Virus infections. Recombinant *Autographa californica* multinuclear polyhedrosis baculoviruses (*AcMNPV*) were passaged in Sf-9 cells (2.0 x 10^6 cells/ml) at low multiplicity of infection (MOI; 0.01). Virus infections for the purpose of recombinant protein production were initiated at an MOI = 5 and maintained for four days until viability reached < 10%. Plaque agarose assays were performed in six-well plates with Sf-9 cell monolayers at 75% confluency by standard methods.

Construction of recombinant baculoviruses. Recombinant baculoviruses (Fig. 11) containing full-length (bHEV ORF2 fl) and a 5'-truncated deletion (bHEV ORF2 5' *tr*) of HEV ORF2 (Pakistan strain) were constructed by standard homologous recombination in Sf-9 insect cells. A recombinant baculovirus containing a 5'- 3' truncation deletion of HEV ORF2 was constructed using bacmid vectors (Luckow, V.A., et al. (1993) J. Virol. 67: 4566-4579) as follows:

Oligonucleotide primers HEV-140 (5'-TTCGGATCCATGGCGGTCGCTCCGGCC-3') (SEQ ID NO: 108) and HEV-141 (5'-TCAAGCTTATCATCATAGCACAGAGTGGGGGGC-3') (SEQ ID NO: 109) were used to clone a 1512 bp PCR-generated DNA fragment encoding HEV ORF2 amino acids 112 through 607 with its own ATG translation initiation codon and multiple stop codons from p61.2 into pCR2.1 (InVitrogen, San Diego, CA) by T/A PCR cloning. A 1520 bp *Bam*HI - *Eco*RI DNA fragment containing HEV ORF2 DNA sequences was inserted downstream of the *polh* promoter within the *polh* locus in the baculovirus donor plasmid, pFASTBAC-1 (Life Technologies, Inc.) Recombinant baculoviruses containing the HEV ORF2 DNA were isolated from Sf-9 cells transfected with the recombinant bacmid DNA using the cationic lipid CELLFECTIN (Life Technologies, Inc.).

° Plaque-purified virus isolates were screened for HEV ORF2 DNA insert integrity and protein expression in insect cells and expanded into a master virus seed bank designated bHEV ORF2 5'-3' *tr* virus.

Infected cell and supernatant processing, Infected cells and supernatant media were harvested at indicated times by centrifugation at 500 x g and 4°C for 5 min. and processed for recombinant HEV ORF2 proteins. Cell lysates were prepared by resuspension of cell pellets in lysis buffer (0.5% NP-40, 50 mM Tris-HCl, pH 8.0, 2 mM EDTA) at 2 ml per mg cell pellet and supplemented with fresh aprotinin to a final concentration of 0.2 mg/ml, vortexed briefly, and incubated for 20 min. on ice. Nuclei were pelleted by low speed centrifugation at 3000 x g and 4°C for 15 min., and the cytoplasmic fraction was collected and used as crude cell lysate. The infected cell supernatants and cell lysates were clarified by centrifugation at 12,000 x g and 4°C for 60 min. using the Sorvall SS34 rotor.

Purification of HEV ORF2 protein products. Recombinant HEV ORF2 proteins were purified from clarified baculovirus-infected cell lysates and supernatant media separately. The crude cell lysate was diluted 1:10 with loading buffer (50 mM Tris-HCl, pH 8.0, 10 mM NaCl).

Clarified infected cell supernatants were concentrated ten-fold by tangential flow ultrafiltration using a spiral wound cellulosic ultrafiltration cartridge (S1Y10; 1 sq. ft. area; 10,000 MW cutoff; Amicon, Beverly, MA) on an Amicon Proflux M-12 ultrafiltration system at a recirculation rate of 4L/min. and a transmembrane pressure of 20 psi. The concentrated supernatant was diafiltered against 4 volumes of loading buffer.

The diafiltrate or diluted crude lysate (1.5 bed vol.) was loaded onto a Q Sepharose Fast Flow strong anion exchange column (XK50 column, 5.0 x 7.5 cm, 150 ml; Pharmacia, Piscataway, NJ) at a flow rate of 5.0 ml/min. The column was washed first with 1.0 bed volume of loading

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buffer at a flow rate of 5 ml/min. followed by a second wash with 1.0 bed volume of loading buffer at a flow rate of 20 ml/min. The proteins were eluted with 6.5 bed volumes of a continuous linear gradient of NaCl from 10 to 300 mM in the same buffer at a flow rate of 20 ml/min.

Ten μl aliquots from Q Sepharose column (Pharmacia, Piscataway, NJ) peak protein fractions were subjected to SDS-PAGE analysis to identify HEV ORF2 (+) protein fractions. Pooled (+) fractions were desalted by gel filtration using Sepharose G-25 (Pharmacia) and loading buffer. The peak protein fraction was collected and loaded onto a Source 15 Q High Performance (Pharmacia) strong anion exchange column to resolve HEV ORF2 polypeptides. The column was washed and eluted as described above for Q Sepharose liquid chromatography. Pooled HEV ORF2 protein (+) fractions were identified as above, pooled, and subjected to a final gel filtration on a Sephacryl S-200 column (Pharmacia) using loading buffer for final protein purification. HEV ORF2 protein fractions were identified by SDS-PAGE and Western blot analyses as described below.

Protein concentrations were determined by the BCA/Pierce microprotein assay at 60^{0}C using bovine serum albumin as a protein standard. All chromatography was performed using a Waters 600E chromatography workstation system (Medford, MA) equipped with Millennium 2010 software for process control and monitoring. Buffer conductivities were determined using an AccuMet 20 conductivity meter. A Corning 220 pH meter was used for determinations of buffer pH.. All buffer components were USP or molecular biology grade raw materials.

SDS-PAGE, and Western blot analyses. Proteins were diluted two-fold in protein denaturation sample buffer (126 mM Tris-HCl, pH 6.8, 5% β-mercaptoethanol, 20% glycerol, 2% SDS, and 0.005% bromophenol blue) and denatured at 99^{0}C for 5 min. Denatured samples were electrophoresed on 8-16% gradient SDS-polyacrylamide gels (NOVEX) (Laemmli, U.K. et al. (1970)

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Nature 227:680-685). Proteins were visualized by staining protein gels with colloidal Coomassie blue stain solution (NOVEX, San Diego, CA) as suggested by the manufacturer.

Proteins were transferred to PVDF membranes by electroblot techniques (Tsarev, S.A., et al. (1993) *J. Inf. Dis.* 168: 369-378). HEV ORF2 products were detected chromogenically by binding to primary antisera (chimp polyclonal α-HEV; 1:500) followed by binding to secondary antisera (goat α-human IgG_2-conjugated to alkaline phosphatase (1:5000; Life Technologies, Inc.). NBT/BCIP (Life Technologies, Inc.) was used as the chromogenic substrate.

Amino terminal sequence analysis. Proteins were subjected to polyacrylamide gel electrophoresis in the presence of SDS using the buffer systems of Laemmli (Laemmli, U.K. et al. (1970) *Nature* 227:680-685). Proteins were transferred electrophoretically from the gel to a Pro Blot membrane (Applied Biosystems, Foster City, CA) according to the manufacturer's instructions. Proteins were visualized by Coomassie blue staining and the 63 kD and 55 kD HEV ORF2 proteins were excised for amino terminal sequence analysis using an Applied Biosystems Model 473 gas/pulsed-liquid phase protein sequencer with on-line PTH analyzer.

Internal amino acid sequence analysis. Proteins were subjected to electrophoresis as described above. Proteins were transferred onto nitrocellulose membranes and visualized with Ponceau S staining. The relevant bands were cut from the membrane and processed for *in situ* proteolytic digestion with Lys C (Boehringer Mannheim, Indianapolis, IN) according to the procedure of Abersold *et al.* (Abersold, R.H., et al. (1987) *Proc. Natl. Acad. Sci. USA* 84:6970-6974). The Lys C derived fragments were isolated using a Waters Associates (Medford, MA) high pressure liquid chromatography system and a Vydac C4 (Hesperia, CA) reversed phase column. The amino acid sequences of the isolated

peptides were determined using an Applied Biosystems model 477A protein sequencer and model 120A on-line PTH analyzer.

Amino acid analysis. The amino acid compositions of the Lys C derived fragments described above were determined following vapor phase hydrolysis in 6N HCl at 150°C for 1 hour using a Waters Pico Tag work station. Amino acids were derivatized with phenylisothiocyanate (PTC) and the resulting PTC amino acids were separated and quantified using a Waters Pico Tag amino acid analysis system.

Carboxy-terminal sequence analysis. Immobilized carboxypeptidase Y (Pierce, Rockford, IL) was used for the sequential release of amino acids from the carboxy-terminus of the 55 kD HEV protein. Approximately 150 μg of the protein in 800 μl of 0.05 M sodium acetate buffer pH 5.5 was mixed with a 200 μl suspension of the resin at 37^{0}C. Aliquots of the supernatant (100 μl) were taken at 0, 5, 15, 30, 60, 90 and 120 minutes. A final aliquot was collected at 16 hours. The samples were dried under vacuum and subjected to amino acid analysis as described above without the hydrolysis step.

Mass spectroscopy. Mass spectrometric detection of purified proteins was performed with a Perkin-Elmer Sciex API-III triple stage quadrupole mass spectrometer (Foster City, CA) equipped with an atmospheric pressure articulated ion spray source. High purity nitrogen served both as the nebulizer gas (operative pressure = 0.5 MPa) and curtain gas (flow rate = 0.8 I/min.). Argon was used as the target gas at a collision gas mass of 3 x 10^{15} atoms/cm^2. The mass spectra scanning range mIz 100-1500 positive ions were obtained by direct infusion of 50 μl/min with a Harvard Apparatus Model 11 syringe pump (Southnatick, MA) of bovine serum albumin standard solutions diluted 1:200 in the mobile phase. Spectra were collected at 1.0 sec intervals. Capillary voltage was maintained at 2 kV and 60°C.

The temporal expression of HEV ORF2 gene products was investigated to identify processed recombinant HEV proteins. Sf-9 insect cells cultivated as suspension cultures in serum-free medium were infected with recombinant baculoviruses encoding full-length hepatitis E virus capsid gene (Pakistan strain) (Figure 11). Cell lysates and media supernatants were harvested from the virus infections daily for four consecutive days. Results of SDS-PAGE and Western blot analyses from HEV cell lysates demonstrated the presence of a HEV ORF2 72 kD protein at one day postinfection (p.i.) that disappeared thereafter (Figure 12). At two days p.i. 63 and 55 kD HEV proteins were present in infected cells. The 55 kD HEV protein became predominant in infected cells at three days p.i. (Figure 12). The abundant protein at 63-65 kD observed at two through four days postinfection was identified as the baculovirus chitinase and not the HEV 63 kD protein. A 53 kD HEV protein was secreted into infected cell media supernatants as soon as one day p.i. and was maximally abundant by three days p.i. These results indicated that a stochastic proteolytic cleavage of the primary 72 kD HEV protein occurred to generate a final 55 kD (cell lysate) or 53 kD (media) HEV protein product.

HEV protein purification. The recombinant HEV 63 and 55 kD proteins were purified by anion exchange chromatography and gel filtration from cell lysates produced by NP-40 lysis of Sf-9 cells infected with recombinant bHEV ORF2 *f1* virus or truncated viruses and harvested at 4 days p.i. The 53 kD secreted protein was purified from media supernatants of harvested virus infections which were clarified by centrifugation and concentrated 10 fold by tangential flow ultrafiltration. Cell lysates and concentrated media supernatants were diluted 10 fold and diafiltered, respectively, with Q loading buffer (50 mM Tris-HCl, pH 8.0, 10 mM NaCl) from cells infected with the 5' doubly travented

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construct. Equilibrated cell lysates (55 kD protein) and media supernatants (53 kD protein) were loaded separately onto a Q Sepharose Fast Flow strong anion exchange column. HEV 55 kD proteins were bound and eluted at an ionic strength of 140 mM NaCl (Figure 13A). HEV protein fractions from chromatographed cell lysates and supernatants were pooled, desalted by passage through a Sephacryl G-25 column, and subjected to a second round of anion exchange chromatography using a SOURCE 15 Q strong anion high performance column. HEV proteins were bound and then eluted at 140 mM NaCl (Figure 13B). HEV protein peak fractions were pooled and fractionated by gel filtration using a Sephacryl S 200 column (Figure 13C). SDS-PAGE and Western blot analyses of the 55 kD protein fractions demonstrated that the 55 kD protein was of HEV origin (Figure 14, lower panel). From Coomassie blue-stained protein gels, the purity of the 55 kD protein was estimated to be 99% or greater (Figure 14A ~~upper panel~~).

Amino terminal sequence analysis. To determine the amino termini of the recombinant HEV 63 and 55 kD proteins detected during bHEV infection of insect cells, amino terminal amino acid sequence analysis was undertaken. Pooled HEV protein fractions were collected from Q Sepharose Fast Flow columns loaded with diluted cell lysates from Sf-9 insect cells infected with bHEV ORF2 *f1* virus and harvested at 2 days p.i. Two HEV proteins were purified from the peak Q fractions at 140 mM NaCl at a ratio of 1:20 (63 kD: 55 kD). Direct Edman degradation of the HEV 63 kD and 55 kD protein bands excised from the ProBlot membrane resulted in an identical amino acid sequence through 20 cycles (Table 9).

Table 9. Amino terminal amino acid sequence analysis of recombinant HEV 63 (SEQ ID NO:110) and 55 (SEQ ID NO:111) kD proteins purified from cell lysates.

T970X

Amino acid analyzer cycle	HEV 55 kD	HEV 63 kD
1	A	A
2	A	A
3	P	P
4	L	L
5	T	T
6	A	A
7	V	V
8	A	A
9	P	P
10	A	A
11	H	H
12	D	D
13	T	T
14	P	P
15	P	P
16	V	V
17	P	P
18	D	D
19	V	V
20	D	D

The sequence corresponded to residues 112 through 131 of open-reading frame 2 of the HEV genome. These results indicated that the difference in apparent molecular weight between the two immunoreactive proteins was due to carboxy-terminal truncations.

Internal amino acid sequence analysis. To determine further the shared identity of the recombinant HEV 63 and 55 kD proteins, peptidase-digestion and fractionation were performed. Purified 55 kD HEV protein was digested with Lys C protease as the specificity of this enzyme for cleavage carboxy-terminal to lysine residues was deemed more suitable than trypsin for peptide production and amino acid sequence determination from the 55 kD HEV protein. The peptide profile of the resulting Lys C digest is shown in Figure 15.

Aliquots of the peaks were subjected to amino acid sequence analysis. Amino acid sequences of internal peptides for the recombinant HEV ORF2 55 kD protein corresponded to the expected amino acid sequence of the HEV ORF2 (Pakistan strain). Peptides containing amino acid sequences from the

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HEV ORF2 amino acid region 607 through 670 were not found. Of particular interest was fraction 24 which yielded 52 cycles of clear sequence corresponding to amino acid residues 554 through 606 of HEV ORF 2. Increases in PTH leucine at cycles 53 or 55 (residues 606 or 608) were not observed, although an increase in PTH alanine was observed in cycle 54. Since > 50 amino acid residues of readable amino acid sequence was not common in our laboratory, it was not clear whether the failure to obtain additional sequence data was caused by a loss of signal due to reaching the end of the peptide (*i.e.*, the carboxy-terminus of the protein) or a failure in Edman chemistry. Therefore, determination of the carboxy terminus of the recombinant HEV ORF2 55 kD protein by several other means was necessary.

Amino acid composition analysis: An alternative means to determine whether amino acids 606 to 608 of the recombinant HEV ORF2 55 kD protein were present in Lys C digestion fraction 24 was amino acid composition analysis of this peptide. The results of amino acid analysis of an aliquot of fraction 24 is shown in Table 10.

Table 10. Summary of amino acid composition analysis of fraction 24 from Lys-C digested HEV 55 kD protein.

Amino Acid	Expected	Observed
Asn + Asp	4	4.4
Gln + Glu	2	3.2
Ser	6	5.7
Gly	4	6.3
His	2	2.1
Arg	1	2.0
Thr	5	5.0
Ala	10	10
Pro	3	3.3
Tyr	4	3.5
Val	6	6.1
Met	0	.7

Cys*	0	0*
Ile	2	2.7
Leu	6	6.3
Phe	0	.6
Lys	0	.9

Normalized to 10 Ala
No derivatization of Cys was performed prior to hydrolysis

This analysis indicated that the failure to obtain amino acid sequence data beyond cycle 54 (residue 607) was due to the fact that amino acid sequencing had reached the carboxy terminus of the 55 kD protein. The results were consistent with the peptide ending at leucine 607. Although this analysis accommodated other minor variations, it demonstrated clearly that the peptide terminated well past an earlier lysine residue (residue 600) in the HEV ORF 2.

Carboxy-terminal sequence analysis. A further means to determine the carboxy terminus of the recombinant HEV ORF2 55 kD protein was carboxy terminal amino acid analysis of carboxypeptidase-digested 55 kD protein. Amino acid analysis of the free amino acids released during a timed incubation with immobilized carboxypeptidase Y revealed a rapid increase in leucine followed by valine, serine, and histidine (Figure 16). No significant increases in the amounts of other amino acids were observed. These results corroborated assignment of the carboxy terminus of the recombinant HEV ORF2 55 kD protein at amino acid leucine 607.

Mass spectrometric analysis. The expected molecular weight of the HEV 55 kD protein (amino acids 112-607 of HEV ORF2) from the nucleotide sequence of HEV ORF2 (Pakistan strain) was estimated at 53 kD. To obtain an absolute mass of this protein, electrospray mass spectroscopy of the purified recombinant HEV 55 kD protein was undertaken. The result from several rounds of MS measurements was that a single

polypeptide with a molecular mass of ~ 56,000 daltons was present in the purified protein preparation (Figure 17). Since mass spectroscopy has a 0.01% degree of accuracy, the conclusion that the HEV 55 kD protein was generated by both N- and C-terminal proteolytic cleavages was corroborated.

Kinetics of HEV ORF2 truncated protein expression in insect cells. To determine whether primary proteins that were deleted at the amino and/or carboxy termini of the HEV ORF2 could be expressed stably and at high levels in insect cells, 5′ and 5′-3′ truncated deletion mutants of the HEV ORF2 were cloned in baculovirus vectors. The results from infections with bHEV ORF2 5′ *tr* and bHEV ORF2 5'-3' *tr* viruses indicated that the 63 and 55 kD proteins were both expressed in insect cells (Figure 18). However, the 55 kD protein became > 50 fold more abundant by three days p.i. in the bHEV ORF2 5′ *tr* infection and was solely present in bHEV ORF2 5′-3′ *tr* virus infections. A 53 kD protein was also secreted into supernatant media within the first day of infection with both viruses and reached maximal levels by three days p.i. The abundance of 53 kD secreted protein was greater than 20 fold more abundant from insect cells infected with the bHEV ORF2 5′-3′ *tr* virus than from cells infected with the bHEV ORF2 5′ *tr* virus. The 55 kD protein was purified from cell lysates from both viral infections and the 53 kD protein was purified from supernatant medium by the purification schemes described above. The amino and carboxy terminus of the secreted 53 kD protein have been identified as amino acids 112 and 578 of HEV ORF2 and the 53 kD protein has been shown to be antigenic in ELISA. The expected molecular weight of the 53 kD protein was 50 kD but the protein was shown to have a molecular mass of approximately 53 kilodaltons by Mass spectroscopy.

Example 17

HEV ORF2 3′ Proteolytic Cleavage Mutant Viruses

Table 11. Summary of HEV ORF2 gene expression results from Sf-9 insect cells infected with bHEV ORF2 3′ proteolytic cleavage mutant viruses generated from bHEV ORF2 fl using standard site directed mutagenesis techniques.

virus mutant	602 A	603 P	604 H	605 S	606 V	607 L	****	613 M	****	634 Q	cell assoc. products	secreted products
I[2]			R								55.63 kD	-
II[2]					A						55.63 kD	-
III[2]			R								63 kD	72 kD low amounts
IV[2]										P	55.63 kD	63 kD low amounts
Va[1]											72 kD	72 kD low amounts
Vb[1]								L			72 kD	72 kD low amounts
VI[2]						P					63 kD	72 kD low amounts

[1] Virus infections harvested at 24 hr. post-infection.
[2] Virus infections harvested at 48 hr. post-infection.

Site directed PCR mutagenesis of the 112-607 bHEV was also conducted using an oligonucleotide primer containing the AUU codon and surrounding nucleotides at amino acid 578 (HEV ORF2 Pakistani strain) to create a substitution of arginine with isoleucine at amino acid 578. Other mutants of the 112-607 bHEV included those with amino acid substitution of arginine with glycine, serine or glutamic acid at amino acid 578. These mutants were constructed as described above using oligonucleotide primers containing codons for the desired amino acid changes. It is believed that these 112-607 bHEV mutants will push the equilibrium of production of HEV ORF2 proteins towards a single protein.

Example 18

Vaccine Studies In Phesus Rhesus Monkeys

Primates. Thirty-two rhesus monkeys (Macacca mulatta) that were HEV antibody (anti-HEV) negative (<1.10) in a sensitive ELISA (Tsarev SA, et al. J Infect Dis (1993);89:369-78) were used in this study.

HEV challenge stock. The Pakistani HEV strain SAR-55 [Iqbal M., et al. J. Trop. Med. Hyg. 1989;40, 438-443] (human feces) or the Mexican HEV strain Mex-14 [Velazquez O, et al. JAMA (1990);263:3281-5] (monkey feces, provided by the CDC) was used as a source of challenge virus. A suspension [in cynomolgus (Macacca fascicularis) seronegative serum] of feces containing the Pakistani or the Mexican HEV strain diluted to contain 10,000 monkey infectious doses (MID_{50}) were used for intravenous inoculation of animals.

Inocula for immunization. 55 kDa ORF-2 protein [Tsarev SA, et al. Prospects for prevention of hepatitis E. In: Enterically transmitted hepatitis viruses. (Y. Buisson, P. Coursaget, M. Kane eds). La Simarre, Joueles-Tours, France, (1996) p. 373-383] purified from infected insect cells (infected with recombinant baculovirus

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containing the complete ORF2) was precipitated with alum as described [Tsarev S.A. et al. Proc Natl Acad Sic USA, (1994);191:10198-202]. The efficiency of precipitation was higher than 99%, as determined by ELISA analysis of the residual soluble antigen. The protein-alum complex was stored at +4°C for up to 1 year.

Inoculation Schedule.

Rhesus monkeys were vaccinated by intramuscular injection of 0.5 ml of vaccine containing 50μg, 10μg, 2μg or 0.4μg of the alum-precipitated 55 kDa protein. Two doses were administered one month apart. Other animals were injected with 0.5 ml of alum suspension lacking the recombinant protein (placebo).

Monitoring of primates. Percutaneous needle biopsies of the liver and samples of serum and feces were collected prior to inoculation and weekly for 15 weeks after inoculation. Sera were assayed for levels of alanine amino transferase (ALT) with commercially available tests (Metpath Inc., Rockville, MD). Biochemical evidence of hepatitis was defined as a two-fold or greater increase in the post-inoculation/pre-inoculation ratio of ALT. Liver biopsy was performed and histopathology was scored as described [Tsarev S.A. et al. Proc Natl Acad Sci USA, (1994);191:10198-202]. clinical evaluation of the animals was performed blindly. The anti-HEV ELISA, and reverse transcriptase-polymerase chain reaction (RT-PCR) were performed as described [Tsarev S.A. et al. Proc Natl Acad Sic USA, 1994;191:10198-202]. For quantification, PCR-positive consecutive sera or feces from each animal were combined and serially diluted in ten-fold increments in calf serum. One hundred μl of each dilution were used for RNA extraction and RT-PCR. The PCR protocol used in this study could detect as few as 10 MID_{50} of HEV per ml of serum and as few as 100 MID_{50} per gram of feces.

Statistical Analysis. Student t-tests were used for pairwise comparison of quantitative parameters of

hepatitis and HEV infection for a placebo group versus the post-exposure vaccination group, and for a placebo group versus the group challenged with the heterologous virus. The Dunnett test was used for multiple comparison of the placebo group versus groups vaccinated with different doses of the recombinant vaccine. The Tukley test was used for multiple comparisons of anti-HEV titers at the time of challenge in animals vaccinated with different doses.

For statistical analysis, serum samples that contained <10 HEV genomes in 1 ml of serum were assigned a titer of 1:1 and fecal samples that contained <100 HEV genomes in 1 g of feces were assigned a titer of 1:10.

RESULTS

Hepatitis E infection in the placebo groups. Each of the four rhesus monkeys vaccinated with alum alone and challenged with the SAR-55 strain of HEV developed hepatitis: post/pre peak ALT ratios in these animals were significantly higher than the cut-off value of 2.0 and ranged from 3.1 to 10.6 (Table 12).

Table 12. HEV infection in rhesus monkeys inoculated with a placebo or with different amounts of the recombinant HEV ORF-2 protein prior to challenge with homologous virus.

Vaccination (Sar-55 ORF-2 protein)					Challenge (Sar-55 strain)			
Inocula and animals	Anti-HEV titer after one vaccine dose	Anti-HEV titer at time of challenge (two vaccine doses)	Post/pre ratio of peak ALT	Histopath-ology (cumulative score)	HEV genome in serum*		HEV genome in feces*	
					Log_{10} titer†	Number of weeks	Log_{10} titer†	Number of weeks
Placebo								
Rh 6051	<1:10	<1:10	3.1	4.5+	4	6	6	6
Rh 6067	<1:10	<1:10	3.9	6.0+	4	5	8	7
Rh 5984	<1:10	<1:10	10.6	5.0+	4	5	6	7
Rh 5985	<1:10	<1:10	8.5	4.5+	3	5	6	5
Vaccine								
2 x 50 μg								
Rh 6068	1:10,000	1:10,000	1.1	0+	2	3	3	4
Rh 6063	1:1,000	1:10,000	1.2	0+	3	2	4	3
Rh 6074	1:10,000	1:10,000	1.1	0+	<1	0	2	1
Rh 6071	1:1,000	1:1,000	1.1	0+	2	5	5	6
Vaccine								
2 x 10 μg								
Rh 5991	1:1,000	1:1,000	1.4	0+	3	6	4	5
Rh 5989	1:1,000	1:10,000	1.1	0+	3	4	3	5
Rh 5974	1:1,000	1:10,000	1.0	0+	2	6	4	7
Rh 5972	1:1,000	1:1,000	0.9	0+	<1	0	3	1

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Vaccination (Sar-55 ORF-2 protein)					Challenge (Sar-55 strain)			
Inocula and animals	Anti-HEV titer after one vaccine dose	Anti-HEV titer at time of challenge (two vaccine doses)	Post/pre ratio of peak ALT	Histopath-ology (cumulative score)	HEV genome in serum*		HEV genome in feces*	
					Log_{10} titer†	Number of weeks	Log_{10} titer†	Number of weeks
Vaccine								
2 x 2 μg								
Rh 5976	1:1,000	1:10,000	1.0	0+	2	3	5	2
Rh 5978	1:1,000	1:10,000	0.9	0.5+	2	5	4	5
Rh 6049	1:100	1:1,000	1.2	0+	2	4	3	4
Rh 6050	1:100	1:100	1.0	0+	2	2	3	3
Vaccine								
2 x 0.4 μg								
Rh 5986	1:100	1:1,000	1.2	0+	2	1	3	1
Rh 5987	<1:100	1:1,000	0.9	0+	1	2	2	1
Rh 5988	1:100	1:10,000	1.1	0+	2	2	2	2
Rh 5992	1:100	1:1,000	1.1	1.0+	2	2	3	3

* As measured by RT-PCR

† Determined on pooled positive samples.

Hepatitis was confirmed by the results of the histologic tests. The cumulative histopathology score ranged from 4.5+ to 6.0+. Viremia and virus excretion were monitored in each animal. Viremia was present for 5 to 6 weeks and virus was excreted a total of 5 to 7 weeks. Positive serum or fecal samples were combined and HEV genome titers were determined in those pools for every animal. The HEV genome titer ranged from 10^3 to 10^4 in pooled sera and from 10^6 to 10^8 in pooled fecal samples. The HEV genome titers were comparable to those we reported previously for cynomolgus monkeys challenged with the same SAR-55 strain of HEV (Tsarev S.A. et al. Proc Natl Acad Sci USA, (1994);191:10198-202). Duration of viremia and virus excretion were also comparable.

Each of the four animals challenged with the Mex-14 strain of HEV developed hepatitis with quantitative parameters of disease, excepting histopathology scores, similar to those of animals challenged with the SAR-55 strain (Table 13).

Table 13. HEV infection in rhesus monkeys inoculated with a placebo or with different amounts of the recombinant HEV ORF-2 protein prior to challenge with homologous virus.

Vaccination (Sar-55 ORF-2 protein)					Challenge (Sar-55 strain)			
Inocula and animals	Anti-HEV titer after one vaccine dose	Anti-HEV titer at time of challenge (two vaccine doses)	Post/pre ratio of peak ALT	Histopath-ology (cumulative score)	HEV genome in serum*		HEV genome in feces*	
					Log_{10} titer†	Number of weeks	Log_{10} titer†	Number of weeks
Placebo								
Rh 5996	<1:10	<1:10	4.8	1.0+	4	4	6	5
Rh 6044	<1:10	<1:10	4.7	1.0+	4	4	6	4
Rh 6045	<1:10	<1:10	7.6	1.5+	3	4	7	6
Rh 6046	<1:10	<1:10	2.7	1.0+	3	4	7	5
Vaccine								
2 x 50 μg								
Rh 5982	1:1,000	1:10,000	1.0	0+	1	1	1	2
Rh 5983	1:10,000	1:10,000	0.9	0+	2	3	3	4
Rh 5994	1:1,000	1:1,000	1.0	0+	2	4	5	2
Rh 5995	1:10,000	1:10,000	1.8	0+	<1	0	<2	0

* As measured by RT-PCR

† Determined on pooled positive samples.

Quantitative parameters of infection were also similar in the two groups of animals. Thus, the HEV challenge stocks were able to produce hepatitis in each and every challenged animal and therefore could be used for validation of vaccine efficacy against hepatitis E.

Hepatitis E infection in the post-exposure vaccinated group. Four animals were challenged with the SAR-55 strain. Forty-eight hours after challenge these animals were vaccinated with 50μg dose of vaccine followed by a booster dose (50μg) one month later. Significant differences in parameters of disease or infection were not found in this group compared to the placebo group, with the exception that the duration of viremia and viral excretion were reduced 1.5 fold and 1.7 fold respectively (data not shown).

Vaccination. All primates vaccinated with the 50μg, 10μg or 2μg dose of vaccine and 3 of 4 primates vaccinated with the 0.4μg dose of the recombinant protein seroconverted to HEV after the first immunization (Tables 12 and 13). A direct correlation between vaccine dose and anti-HEV titer was observed following the first dose; a geometric mean (GM) of 1:32 for the 0.4μg dose, 1:316 for the 2μg dose, 1:1,000 for the 10μg dose, and 1:3,200 for the 50μg dose. When the second dose of vaccine was administered, dose-related differences in GM titers were still observed one month after second vaccination, but the range was narrower (between 1:1,800 and 1:5,600 as seen in Table 14).

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Table 14. Summary of HEV infection after homologous or heterologous challenge.

Vaccination (Sar-55 ORF-2 protein)				Challenge Results			
Category (4 animals/ category)	Anti-HEV GM* titer	Post/pre ratio of peak GM* ALT	Histopatho-logy (mean cumulative score)	HEV genome in serum†		HEV genome in feces†	
				GM* titer (log_{10})	Mean number of weeks	GM* titer (log_{10})	Mean number of weeks
SAR-55							
Placebo	<1:10	5.7	5+	3.8	5.3	6.5	6.3
Vaccine							
2 x 50 μg	1:5,600	1.1(S)	0+(S)	1.8(S)	2.5(N)	3.5(S)	3.5(S)
2 x 10 μg	1:3,200	1.1(S)	0+(S)	2.0(S)	4.0(N)	3.5(S)	4.5(S)
2 x 2 μg	1:1,800	1.0(S)	0.1+(S)	2.0(S)	3.5(N)	3.5(S)	3.8(S)
2 x 0.4 μg	1:1,800	1.1(S)	0.3+(S)	1.8(S)	1.8(S)	1.8(S)	2.5(S)
Mex-14							
Placebo	<1:10	4.6	1.1+	3.5	4	6.5	5.0
Vaccine							
2 x 50 μg	1:5,600	0.9(S)	0+(S)	1.3(S)	2.0(N)	2.3(S)	2.0(S)

* Geometric mean.
† As measured by RT-PCR.
(S) Statistically significant difference compared to placebo group ($p<0.05$).
(N) Statistically insiginficant difference compared to placebo group ($p>0.05$).

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Statistical analysis using a multiple comparison test for anti-HEV GM titers indicated that the dose-related differences in GM titers after two doses of vaccine were not significant. At this time the rhesus monkeys were challenged.

Homologous challenges. All 16 animals vaccinated with any of the four doses of vaccine were protected against hepatitis according to the biochemical criterion since none developed elevated serum ALT levels (Table 12). Histological changes were found only in two of the 16 animals and these had received the two lowest doses of vaccine. The histological abnormalities were minimal and in one of these two animals (rhesus-5978) might not even be related to HEV infection because similar abnormalities were found in pre-inoculation liver samples also. Overall, all four groups of animals vaccinated twice with 50μg, 10μg, 2μg or 0.4μg doses of vaccine were protected against hepatitis and quantitative parameters of hepatitis E in each of these four groups were statistically different from those in the placebo group (Table 14).

Although animals in all vaccinated groups were protected against hepatitis E disease, they were not protected against infection with HEV. Even though virus titers in vaccinated animals were statistically lower than those in the placebo groups, duration of viremia and viral excretion were not significantly reduced in the majority of cases. Compared to the placebo group, the level of viremia in the vaccinated animals was reduced about 80-fold and level of viral excretion was reduced about 1,000 fold on average. Two animals were protected against viremia, with the Mex-14 HEV strain, the most genetically and geographically different from the vaccine strain, were protected against hepatitis by administration of two 50μg doses of recombinant vaccine (Table 13). Histological or biochemical evidence of hepatitis was not detected in any of these animals. When immunized animals were compared as a

group to the placebo group, the differences in the expression of disease were statistically significant (Table 14). However, as in the case of homologous challenge, most animals were not protected against infection with HEV. Both viremia and viral excretion were detected in three animals; the fourth animal experienced neither and therefore was completely protected against infection. Levels of viremia and viral excretion were significantly reduced (about 180-fold and 1,800-fold) when compared to animals vaccinated with the placebo. The difference in duration of viral excretion was significant but that of viremia was not.

In sum, these experiments demonstrated that a dose of the recombinant protein as low as 0.4 μg administered twice protected rhesus monkeys from hepatitis. Significant differences in anti-HEV GM titers after two does of vaccine ranging from 0.4 μg to 50 μg were not observed. When challenged with the homologous virus strain, all vaccinated animals were protected against hepatitis E as measured by ALT elevations and only two animals, both of which received the lower dose of vaccine, had minimal histopathology. The protective effect of the vaccine was quantified by multi-group comparison which indicated that, with the exception of the post-exposure vaccinated group, quantitative parameters of hepatitis in all vaccinated primates were lower than those in the placebo group, and this difference was statistically significant. In addition, vaccinated animals which received the 50 μg dose of the vaccine twice, the only dose tested, were protected from heterologous challenge with the most genetically and geographically distant strain of HEV identified to date. In contrast, post-exposure vaccination was not successful. All animals which were vaccinated 48 hours after challenge developed hepatitis according to both biochemical and histological criteria.

Although seropositive primates were protected against hepatitis E after challenge with a high dose of HEV most of them were not protected against HEV infection. This

is perhaps not surprising since this virus, which is normally transmitted by the oral route, was administered intravenously to assure uniformity of exposure. However, extent of infection as measured by levels of viremia and viral excretion was significantly reduced in all vaccinated animals compared to placebo animals. And in fact, one animal challenged with the heterologous strain was completely protected against infection with HEV and two animals challenged with the homologous strain of HEV excreted virus but did not have detectable viremia. The higher percentage of animals completely protected against infection in our previous study (Tsarev S.A. et al. Proc Natl Acad Sci USA, (1994);191:10198-202] might be explained by the fact that in the previous study we used both 1,000 and 10,000 MID_{50} doses of challenge virus while in this study we have used only the higher dose. Since there is a dose-dependent response to HEV infection in primates [Tsarev SA, et al. Prospects for prevention of hepatitis E. In: Enterically transmitted hepatitis viruses. (Y. Buisson, P. Coursaget, M. Kane eds). La Simarre, Joueles-Tours, France, 1996, p. 373-383], the higher dose was chosen to ensure that every non-vaccinated animal developed pronounced hepatitis.

In this and the previous study, it was demonstrated that, without exception, the viral titer in the serum was lower than that in feces (about 1,000-fold on average) in all placebo and vaccinated primates. That finding is consistent with the fact that HEV is transmitted by the fecal-oral route. In every vaccinated animal decreased levels of viremia and viral excretion were observed when compared to placebo animals. However, duration of viremia, although shorter in all vaccinated primates, was not significantly reduced compared to that in the placebos in most cases. Viremia has always paralleled HEV excretion in feces in the several dozen primates investigated. Therefore, serum samples might be used as the primary indicator of viral infection with the titer

reflecting the level of HEV infection. That is an important observation because serum samples are usually more readily available than fecal samples.

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